About Interlocks, Timing Systems and how to send SPS beams to the LHC

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The SPS has **3 Hardware Interlock Systems**, all based on the same HW components (permit loops and Beam Interlock Controller (BIC) modules):

- The ring beam interlock acts by triggering the SPS beam dump. This system also covers the North transfer line and LSS2 extraction area.
- The LSS4 extraction interlock system acts by inhibiting the extraction kicker MKE4. It covers LSS4 and the TT40, TT41 and TI8 lines.
- The LSS6 extraction interlock system acts by inhibiting the extraction kicker MKE6. It covers LSS6 and the TT60 and TI2 lines.

The intrinsic reaction time of the HW Interlock Systems is at the level of some microseconds, and the system is designed for high reliability and safety.

Ideally protection should rely (almost) entirely on the HW Interlocks Systems:

- This is the case for the SPS ring and for the fast extractions and the transfer lines that are behind (TT40, TI8, TT41, TT60 and TI2).
- There are however significant weaknesses for the slow extracted FT beams at the level of LSS2 and of the TT20 transfer line. The holes in the system are filled by the Software Interlock System.
The SPS Software Interlock System (SIS):
- Surveys all parts of the SPS 'complex'.
- Sets Software Interlocks at the level of the BIC modules of the HW interlock systems (input for SIS):
  - beam dump trigger or extraction inhibit.
  - reaction time: ~immediate.
- Sets Software Inhibits at the level of the SPS Master Timing Generator (MTG):
  - inhibits the beam in the SPS injectors (beams go to 'spare').
  - beam is no longer sent to the SPS.
  - reaction time: one or more cycles (given by the MTG/CBCM reaction time).
SIS Basics

- SIS monitors ~ 1000 parameters, states and settings covering the SPS and its transfer lines.
- The acquired values are analyzed (tested) and converted into a logical state (TRUE or FALSE).
- The logical states are grouped into tree-like structures and combined using logical operators (AND or OR). In the simplest case an 'AND' of all conditions is performed.
- The top of the tree corresponds to a SOFTWARE PERMIT (SW_PERMIT) which itself is either TRUE or FALSE:
  - TRUE: OK for beam operation.
  - FALSE: one or more tests indicate an abnormal situation.

  >>> the status of the SW_PERMIT is exported to HW interlock and timing systems.

- The SW_PERMIT depends on the SPS beam modes:
  - Some tests are masked out automatically in certain modes.
  - SIS will ALWAYS check that the beam mode is consistent with the state of some key elements (TEDs and extraction elements). If an inconsistency is detected, one or more SW_PERMITs will automatically return FALSE and stop all beams affected by such an inconsistency.
SIS & the Timing System

The interaction of SIS with the SPS MTG is ruled by:

1/ The SIS INHIBITs that are defined in the timing system.

2/ The beam DESTINATION that is set for each beam.

3/ A truth-table linking INHIBITS and DESTINATIONs.

The following slides will (hopefully) clarify those 3 aspects.
Beam Destinations and Masterships
Beam Destinations

- Each 'beam' defined the timing system has a **DESTINATION**.
- The **DESTINATION** may be:
  - **STATIC**: it is defined once and for all and will be set every time the beam is executed. Static destinations are used for FT and CNGS beams.
  - **DYNAMIC**: the destination is not predefined, but is set dynamically according to the requests, for example when the LHC is master of the beams. Dynamic destinations are used for LHC beams. By default the LHC beam destination is SPS_DUMP.
  - For a beam with a static destination : dynamic destination = static destination.
  - When a beam cannot be executed (no request or inhibit set anywhere in booster, CPS or SPS), the spare beam is executed and the destination is set to SPS_DUMP.

<table>
<thead>
<tr>
<th>Beam</th>
<th>Static Destinations</th>
<th>Dynamic Destinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Target</td>
<td>SPS_DUMP FTARGET</td>
<td>FTARGET</td>
</tr>
<tr>
<td>CNGS</td>
<td>SPS_DUMP CNGS</td>
<td>CNGS</td>
</tr>
<tr>
<td>LHC</td>
<td>SPS_DUMP</td>
<td>TI2_DUMP, TI8_DUMP, LHC1_TI2, LHC2_TI8</td>
</tr>
</tbody>
</table>
Static Destinations

The static destinations for FT and CNGS beams are set at the level of the Booster beam. The other machines 'inherit' the destination.

To set the destination:

- Select the sequence from the sequence manager and edit the sequence.
- Select the beam at the level of the Booster.
- Right click to get a selection menu.
- Select 'Edit Options'.
- Set the destination in the appropriate menu.
- Save the sequence and send it.

>> See the following slides
The static destination FTARGET and CNGS at the level of the booster.
Right click on the beam at the level of the PSB to get the popup menu, select 'Edit Option'.
A beam is defined as 'LHC beam' in the timing system when the **TO-LHC** bit is set.

A beam with this bit set will have its **DYNAMIC** destination set according to either the request set by the Sequencer Manager or by the **LHC MTG**.

To set this bit:
- Select the sequence from the sequence manager and edit the sequence.
- Select the beam at the level of the SPS.
- Right click to get a selection menu.
- Select 'Edit Cycle Options'.
- Set the TO_LHC flag in the 'Misc' option.
- Save the sequence and send it.

>>> See the following slides
The **TO_LHC** flag is set for the beam [green] but not for the spare [yellow].
Sequence Edition: TO_LHC

- Right click on the beam to get the popup menu,
- select 'Edit Cycle Option'
- Select the MISC option and set/unset the TO_LHC flag.
Setting the Dynamic Destinations

- The TI2_DUMP and TI8_DUMP destinations are set in the menu, by clicking on the Status column.
- Note that if R_S.TI2_DUMP and R_S.TI8_DUMP are ACTIVE at the SAME TIME, then the destination will remain SPS_DUMP. Only one destination may be set at a time.
- The LHC1_TI2 and LHC2_TI8 destinations are set through the LHC MTG (under LHC control) - see later.
LHC Mastership

• For the LHC to gain mastership on a LHC beam (TO_LHC flag set), use this LHC injection sequencer application.

• This application also controls the actual requests when LHC is master.
Switching to LHC mastership

To switch to LHC mastership for SPS USER LHCxxxx, follow the steps:

1. Remove the request for LHCxxxx. Set R.LHCxxxx off in the SPS sequence editor, external conditions tab, right column (see slide 17).
2. Open the LHC injection sequencer application (previous slide) and request mastership.
3. Be patient… takes a few SPS supercycles.
4. Once the LHC mastership is pending, set the request R.LHCxxxx active again.
   - You can verify whether the mastership request is pending on the TGM video. “LSR CTRL” comes on - see next slide)
   - When the you really have the mastership both “LSR CTRL” and “LSO CTRL” are visible on the TGM video for the LHC cycle in the SPS
LHC mastership diagnostics / I

- Use the SPS TGM video application to check the mastership status.
- The mastership status appears on the line 'LHCSEQ'.
- In the example below, LHC is master and a request for ring 1 (R1) is pending (1 'batch').

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LHC is master : 'LSR_CTRL'
Request for Ring 1, 1 batch
In the figure below, LHC is master and a request for ring 1, 1 'batch' is EXECUTED (second line).

Dynamic destination is LHC1_TI2 !
Releasing LHC mastership

To switch back to SPS mastership for SPS USER LHCxxxx, follows the steps:

- Remove the request for LHCxxxx. Set R.LHCxxxx off in the SPS sequence editor, external conditions tab, right column (see slide 15).
- Open the LHC injection sequencer application (previous slide) and remove mastership.
- Be patient... takes a few SPS supercycles.
- Once LHC has no more mastership (see also TGM video), set the request R.LHCxxxx active again.
SIS and MTG
The SIS PERMITs reflect the logical segmentation of the SPS ‘complex’ into its components: the ring and the transfer lines. The permit structure is designed to provide a flexible inhibit scheme for the SPS.
SIS Permit Trees

- The BIC column indicates if the PERMIT is applied to a BIC module (HW intlk).
- The timing inhibit is the name of the inhibit signal at the level of the MTG/sequence manager.

<table>
<thead>
<tr>
<th>PERMIT TREE</th>
<th>AREA</th>
<th>TIMING INHIBIT</th>
<th>BIC</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS_SW_PERMIT</td>
<td>SPS ring + TT10 + extractions</td>
<td>I_S.SIS_RING</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TT20_SW_PERMIT</td>
<td>LSS2 extr + TT20 + North targets</td>
<td>I_S.SIS_TT20</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TT40_SW_PERMIT</td>
<td>LSS4 extr. + TT40</td>
<td>I_S.SIS_TT40</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TI8_SW_PERMIT</td>
<td>TI8 to downstr. TED</td>
<td>I_S.SIS_TI8_DUMP</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>INJ2_SW_PERMIT</td>
<td>TI8 after downstr. TED</td>
<td>I_S.SIS_TI8_INJ</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TT41_SW_PERMIT</td>
<td>TT41 + CNGS target</td>
<td>I_S.SIS_TT41</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TT60_SW_PERMIT</td>
<td>LSS6 extr. + TT60</td>
<td>I_S.SIS_TT60</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>TI2_SW_PERMIT</td>
<td>TI2 to downstr. TED</td>
<td>I_S.SIS_TI2_DUMP</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>INJ1_SW_PERMIT</td>
<td>TI2 after downstr. TED</td>
<td>I_S.SIS_TI2_INJ</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>MKP_SW_PERMIT</td>
<td>SPS ring</td>
<td>----</td>
<td>NO</td>
<td>Inhibits the injection kicker MKP when SPS is OFF (protection against erratics)</td>
</tr>
<tr>
<td>MKP_SFT_SW_PERMIT</td>
<td>SPS ring</td>
<td>----</td>
<td>NO</td>
<td>Inhibits the injection kicker MKP on FT beams</td>
</tr>
<tr>
<td>MKP_CNGS_SW_PERMIT</td>
<td>SPS ring</td>
<td>----</td>
<td>NO</td>
<td>Inhibits the injection kicker MKP on CNGS beams</td>
</tr>
<tr>
<td>SPS_ALARM</td>
<td>All</td>
<td>----</td>
<td>NO</td>
<td>Only used for ALARMS</td>
</tr>
</tbody>
</table>
SIS Permits Information

Click on / select a PERMIT to obtain this information.

The timing inhibit that is controlled by the selected SW PERMIT

BIC module where the selected SW PERMIT is applied.

The PERMIT is evaluated/refreshed for those SPS cycles (USERs).
SIS Inhibits in the Sequence Manager

<table>
<thead>
<tr>
<th>Hardware Conditions</th>
<th>Status</th>
<th>Name</th>
<th>Priority</th>
<th>Status</th>
<th>Software Conditions</th>
<th>Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.SPS</td>
<td>OK</td>
<td>I.SPS, TT60</td>
<td>SOFT</td>
<td>OK</td>
<td>S.SPulse</td>
<td>ACTIVE</td>
<td></td>
</tr>
<tr>
<td>I.S.PROT</td>
<td>OK</td>
<td>I.SPS, TT40</td>
<td>SOFT</td>
<td>OK</td>
<td>S.Pulse</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>I.S.DON</td>
<td>OK</td>
<td>I.SPS, TT2, INJ</td>
<td>SOFT</td>
<td>OK</td>
<td>S.DON</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>I.S.DMD</td>
<td>OK</td>
<td>I.SPS, TT2, BNG</td>
<td>SOFT</td>
<td>BAD</td>
<td>S.DMD</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>I.S.DUMP</td>
<td>OK</td>
<td>I.SPS, TT41</td>
<td>SOFT</td>
<td>OK</td>
<td>S.DUMP</td>
<td>ACTIVE</td>
<td></td>
</tr>
<tr>
<td>I.S.FEARGET</td>
<td>OK</td>
<td>I.SPS, TT2, DUMP</td>
<td>SOFT</td>
<td>OK</td>
<td>S.FEARGET</td>
<td>ACTIVE</td>
<td></td>
</tr>
<tr>
<td>I.S.CNG5</td>
<td>OK</td>
<td>I.SPS, TT2, DUMP</td>
<td>SOFT</td>
<td>OK</td>
<td>S.CNG5</td>
<td>ACTIVE</td>
<td></td>
</tr>
<tr>
<td>I.S.T12</td>
<td>OK</td>
<td>I.SPS, TT70</td>
<td>SOFT</td>
<td>OK</td>
<td>S.T12</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>I.S.T8</td>
<td>OK</td>
<td>I.SPS, TT8, INJ</td>
<td>SOFT</td>
<td>OK</td>
<td>S.T8</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>BAD</td>
<td>R.S.LHC, R4</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>BAD</td>
<td>R.S.LHC, R4</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>BAD</td>
<td>R.S.LHC, R4</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>BAD</td>
<td>R.S.LHC, R4</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>R.S.LEO, R4</td>
<td>BAD</td>
<td>BAD</td>
<td>R.S.LHC, R4</td>
<td>OFF</td>
<td></td>
</tr>
</tbody>
</table>

---

Note: The image contains a detailed view of the Sequence Manager interface, showing various hardware and software conditions with corresponding statuses.
The matrix below indicates which INHIBITs affect a beam with a given DESTINATION (YES).

- Empty table cells mean that the INHIBIT has no effect on the DESTINATION.
- The ring inhibit affects all destinations, since every beam passes through the ring!
- Only inhibits corresponding to (parts of) transfer lines that are used for a given DESTINATION are relevant.

- Example: if I_S.SIS_TT40 is FALSE/BAD, all beams passing through TT40 will be stopped: CNGS beams and LHC beams for TI8 and LHC ring2. Other beams are unaffected!

<table>
<thead>
<tr>
<th></th>
<th>SPS_DUMP</th>
<th>FTARGET</th>
<th>CNGS</th>
<th>TI8_DUMP</th>
<th>LHC2_TI8</th>
<th>TI2_DUMP</th>
<th>LHC1_TI2</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_S.SIS_RING</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>I_S.SIS_TT20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_S.SIS_TT40</td>
<td></td>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_S.SIS_TT41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>I_S.SIS_TT60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>I_S.SIS_TTI2_DUMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_S.SIS_TTI2_INJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
</tr>
</tbody>
</table>
Sending beam to the LHC and Tix lines

First step: SIS and SPS beam mode.

- Make sure the SPS beam mode is consistent with the state of extraction elements and transfer line TEDs.
- If the states are not consistent SIS will inhibit the beam.

<table>
<thead>
<tr>
<th>LHCB2 mode</th>
<th>LHC1 mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO EXTRACTION</td>
<td>NO EXTRACTION</td>
</tr>
<tr>
<td>LHC RING 2</td>
<td>LHC RING 1</td>
</tr>
<tr>
<td>Extraction elements on, TT40 TED in beam</td>
<td>Extraction elements on, TT60 TED in beam</td>
</tr>
<tr>
<td>Extraction elements on, TT40 TED out of beam, TI8 TED in beam</td>
<td>Extraction elements on, TT60 TED out of beam, TI2 TED in beam</td>
</tr>
<tr>
<td>LSS4 extraction elements: • CNGS active → on • CNGS no active → off</td>
<td>LSS6 extraction elements off</td>
</tr>
<tr>
<td>TT60 TED</td>
<td>TT60 TED</td>
</tr>
<tr>
<td>Extraction elements on, TT60 TED in beam</td>
<td>Extraction elements on, TT60 TED in beam</td>
</tr>
<tr>
<td>TI2 TED</td>
<td>TI2 TED</td>
</tr>
<tr>
<td>Extraction elements on, TT60 TED out of beam, TI2 TED in beam</td>
<td>Extraction elements on, TT60 TED out of beam, TI2 TED in beam</td>
</tr>
</tbody>
</table>
Sending beam to the LHC and Tix lines

**Second step**: Inhibits and interlocks.

- All transfer line elements up to the last element seen by the beam must be in the correct state for both SIS and the extraction BIS to give green light for beam.
  
  » Check all relevant SIS PERMIT are TRUE !

- If the beam is stopped on one of the TEDs, only the elements up to the TED are taken into account in the SIS and BIS decisions.

- Do not forget to remove the TI2-DUMP and TI8-DUMP inhibits (hardware) buttons !!

**Third step**: Beam request.

- You are now in a position to request the beam, either under SPS or LHC mastership. In case of doubts use the TGM video application to verify that the dynamic destination is set. If this is the case, then the absence of beam is not due to the timing system !!!

- Even under LHC mastership, it is possible to extract to any of the SPS TEDs (and not just to the LHC itself), provided TED states and beam mode are consistent !

- Do not forget to enable the SPS injection and extraction kickers !

- The extraction BIS interlocks do not affect the production of the beam (it should be injected into the SPS): it only potentially affects the extraction.
Warning!

- All aspects related to the timing system depend on the DESTINATION that is set for a beam: the correct logic is only applied if the destination is set correctly.
- Since the DESTINATION is set manually (by us), **NOTHING PREVENTS ANYONE FROM GIVING ANY BEAM ANY DESTINATION!**
  - You can set a CNGS destination for an LHC beam and vice-versa!

>> This is the one if the reasons why SIS also acts on the HW interlock systems since they will ensure that the machine remains safe.

- When the DESTINATION is incorrect:
  - SIS will only stop the beams by the HW interlock systems.
  - The beams will not be stopped in the CPS: they will continue to come down TT10.
  - Depending on the conditions, the beam will
    - go to the injection dump when the ring interlock system is triggered (MKP inhibit).
    - go the SPS beam dump (standard dump) when the extraction interlock system is triggered (MKE4 or MKE6 inhibit).
More Warnings for MD Beams!

- The inhibits within the MTG apply even when the beams are not extracted!

A concrete example:
- LHC cycle in the SPS is running an MD beam (parallel or dedicated).
- There is no extraction, the beam is only used in the SPS.
- The beam is flagged as TO_LHC.
- Its dynamic destination is set to TI8_DUMP.

>> If a SW PERMIT related to TT40 or to TI8 sets an inhibit, then the beam will be stopped, even if it is not extracted!!

To avoid such 'effects':
- Always set the Beam mode to 'NO-EXTRACTION' in such situations, and make sure the extraction elements are safe (as seen by SIS).
- Do not set the R_S.TI2_DUMP and R_S.TI8_DUMP requests to active (see one of the previous slides).