Personnel Protection of the CERN SPS North Hall in Fixed Target Primary Ion Mode

While CERN’s Super Proton Synchrotron (SPS) is able to deliver both secondary proton and primary ion beams to fixed targets in the North Area, the experimental areas (North Hall) are widely accessible during beam. In ion mode all normal safety elements involved in producing secondary beams are removed, so that an accidental extraction of a high-intensity proton beam into the North Hall would expose personnel to a radiation hazard. This has required an injector reconfiguration restricting operation to either ions or protons. However, demands for operational flexibility of CERN accelerators have led to a need to mix within the same SPS super-cycle both high-intensity proton cycles for LHC or HiRadMat and ion cycles for the North Area. We present an active interlock designed to mitigate this hazard: Beam Current Transformers are used to measure the beam intensity, and if above a set threshold, pulsing of the extraction septa is vetoed. The safety function is implemented by means of two logically equivalent but diverse and separate interlock chains. This interlock is expected to be in place once the SPS resumes operation after the first Long Shutdown in 2014.

**Future Operation of the SPS**
- CERN Super Proton Synchrotron (SPS) accelerates protons and heavy ions (Pb, Kr, Ar) of various energies and intensities.
- Two main modes: proton mode for pure proton beam and ion mode for mixed proton and heavy ion operation.
- Several cycle types can be used:
  - High intensity protons to LHC or TT
  - High intensity protons into TT46 tunnel with fast extraction to TT46 (p = 450 GeV/n, $I_{max} = 6.10^{13}$)
  - High intensity protons to HIRadMat with fast extraction to TT46 (p = 450 GeV/n, $I_{max} = 10^{13}$)
  - Low intensity ions to North Hall with slow extraction to TT46 ($p = 33 - 516$ GeV/n, $I_{max} = 1.610^{10}$)
- Acceleration cycles to different destinations are organized into super cycles.

**Hazard Scenario – What We Must Protect Against**
- When the SPS is in its primary ion mode, various absorbers and collimators used to produce secondary beams in the North Area are removed to allow primary beam to reach the target areas.
- The North Area experimental facilities are accessible during beam. Therefore, erroneously extracting a high-intensity proton beam towards the North Area on an ion cycle would expose people there to a radiation hazard. This could happen due to a cycle processing or filling error while the probability is low, it cannot be completely excluded.
- An erroneous extraction could proceed as follows:
  1. The extraction line TT20 is characterized to receive an ion beam of fixed energy.
  2. A proton beam destined to, say, the LHC or HIRadMat is injected into the SPS.
  3. With beam ions running, ramping septa. Before reaching the beam energy corresponding to the parameterization of the TT20 line an extraction is triggered towards the North Area.
  4. Given a slow extraction taking up to 30 s, a fraction of the beam depending on the ramp speed and the energy tolerance of the beam line bending magnets (plus-minus around 2%) would reach the target area.

**Components of the SPS and the Ion Interlock**

**Design of the Safety System – Principle of Protection**
- The interlock is to be independent of the beam control system and any related timing information.
- The safety system will only be active in ion mode. A key switch in the CCC selects intensity ions to North Hall with slow extraction to TT46 intensity protons to HiRadMat with fast extraction to TT46.
- During an ion run the interlock will be solicited continuously. Given the proposed annual SPS run time in ion mode, the interlock switching count will likely amount to some 1-2 million annually.
- The response time of the safety system should remain below 570 ms corresponding to the worst case of injecting a high-intensity proton beam on an ion cycle set to the lowest energy.

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- **A key switch in the CCC selects intensity ions to North Hall with slow extraction to TT46 intensity protons to HiRadMat with fast extraction to TT46**.
- **During an ion run the interlock will be solicited continuously**.
- **The safety function is implemented by means of two logically equivalent but diverse and separate interlock chains**.

**Expected System Performance**
- BCTs: < 20 ms from measurement to output.
- Interlock: < 25 ms wired chain, < 55 ms PLC chain.
- MSE/MST power converters: > 20 ms to safe state.
- Total reaction time to critical event: < 560 ms.

**References**

**Beam Current Transformers**
- The beam current transformers are of type Direct Current Current Transformer (DCT), which measures the mean value of the total beam current, corresponding to the flow of charged particles, continuous in case of a coast beam or discontinuous in case of a bunched beam.
- The BCT substrates are designed to send signal when the measured intensity is below the set charge threshold of 2.1013.
- BCTs are designed and built at CERN.
- They are implemented in hardware with no remote manipulation possible.
- A self-diagnostic facility to automatically assess equipment status.
- Two identical DCTs are installed as part of the safety system.
- One fast BCT, which measures instantaneous current, installed for monitoring.

**Beam Current Transformers**

- Right: Each DCT delivers two status signals to the interlock, which indicate the level of beam intensity and the state of health of the DCT.

**Interlock and Signal Paths**
- Interlock design done respecting as much as possible the norm IEC 61511.
- Redundancy and diversity are provided by two separate safety chains implementing the same logic but with different technologies.
- A chain A is based on Siemens 37 PLC with Profibus DP fiber channel (C)/O.
- A chain B is based on HIMA Planar/series and connected to HIMA logic by an optical coupler.
- Wired signal paths either double-complementary (ambidextrous) or divergent to trip (fail safe). For isolation, optocouplers are used for durability.

**Interlock and Signal Paths**

- Left: A typical SPS super cycle during a primary ion mode run, comprising a North Area ion cycle at 80 GeV/n, a HIRadMat cycle at 400 GeV/n, and in case of BCT failure at 450 GeV/n. The blue line represents the magnetic rigidity, the green line (red above the 2×1013 threshold) the number of changes. The threshold level (dotted line) is exaggerated for the drawing to be readable. The momentum scale is in GeV/n, the time scale in ms.

**MSE/MST Extraction Elements**
- The power converters of the extraction septum MSE2181BM and the first dipole MEG277 foil act as actuators to the safety system.
- The interlock normally holds a signal high to allow extraction. When the beam intensity exceeds the threshold, the interlock logic cuts this signal low.
- A current card on the power converters will then set the current reference from the SPS power converter control system (MST) to its minimum value causing immediate discharge of the extraction elements.
- A supplementary DCT is installed to measure the power converter current. If it detects that the current hasn’t decreased to the level required after a delay, it signals an error, which is delivered to the beam control system by the interlock logic to signal beam to be dumped.
- Any internal error condition must be reset with key by the safety officer after investigation before continuing operation.

**MSE/MST Extraction Elements**

- Above: Power converter signal diagram. The reference is sent as an analog signal directly from the SPS power converter control system (MST). Interlock signals from both PLC and wired channels are shown as well as the internal safety-check signals from the supplementary DCT installed.

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