66th Meeting of the Machine Protection Panel

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1 Presentations

The slides of all presentations can be found on the website of the LHC and SPS Machine Protection Panel:
http://lhc-mpwg.web.cern.ch/lhc-mpwg/

1.1 Short introduction to LINAC4 – (B. Mikulec)

- Linac4 has to provide different beams to the PSB every 1.2s with varying intensities (by orders of magnitude), interleaved by cycles to measure the lines. This is very different to the operation of the LHC. The interlock system has to deal with many different destinations. If one beam line to a certain destination is in fault the others should potentially still be served.
- The Interlock design needs to take PSB external conditions into account to make optimal use of the facility.
- It has been shown that one worst-case beam loss (of a single pulse) is not going to destroy the beam pipe. But certain dumps cannot stand more than one full beam pulse, thus the BIS design has to exclude more than one full beam pulse loss.
- Motivations for Linac4 are the ageing of Linac2, increased luminosity for LHC, phase space painting in PSB due to H^-.
- Source: The H^- source needs to continuously pulse to assure intensity stability. Design values are: 65mA, 400μs pulse length, 0.83Hz repetition rate. Note: Only the source BIC will cause a stop of the source in case of a false BEAM PERMIT. After this an intervention will be needed.
- Pre-Chopper: The pre-chopper (rise/fall-time ~2μs) regulates the beam extraction. This is regulated by four timings ([1] start 1ms before source RF; [2] stop for beam passage; [3] start to cut beam passage; [4] stop after source RF off). Timing 3 is also used to shorten the Linac4 beam length for

lower intensities, as some BI equipment does not cope with the bunch length from Linac4.

- The pre-chopper is a main BIS actor (together with chopper). The pre-chopper provides a USER_PERMIT to the source RF Master BIC.
    - Markus asks if there is a hardware interlock foreseen. Bettina responds that a hardware interlock is foreseen in case the BI equipment (e.g. wire scanner, etc.) is in, when using the pre-chopper to cut the beam ([3]).
- RFQ: The RFQ was produced at CERN and is a 3m long brazed-copper 4-vane structure. It provides bunching and the acceleration of the beam from 45keV to 3MeV. Installation into the Linac4 tunnel is planned for end summer 2013. It is still to be clarified if the RFQ could be added as USER_PERMIT to the source RF Master BIC.
- Beam stopper: The beam stopper is too slow for ppm action of the BIS, but is used by the personnel safety system.
- Chopper Line (3MeV): The chopper line consists of 3 bunchers and matching sections at the beginning and end. It is an electrostatic beam deflector followed by an internal dump. The goal is to chop holes into the beam (~5ns rise and fall time):
    - Remove head/tail of the Linac4 pulse.
    - Match booster acceptance, to inject directly into PSB buckets.
    - Chop beam during rise-time of ~1μs between distributor levels.
- The chopper is the main Linac4 BIS actor and provides a USER_PERMIT to the source RF Master BIC.
- Installation is foreseen end of 2013.
- Drift Tube Linac (DTL): The DTL consists of 3 tanks with 108 permanent magnets. To be installed beginning 2014.
- Cell-Coupled Drift Tube Linac (CCDTL): 7 modules of DTL-type cavities connected by coupling cells.
- Pi-Mode Structure (PIMS): 12 7-cell copper cavities operating in pi-mode. The last two modules are used for longitudinal painting. Installation planned for 2015.

- Combined RF status of all klystrons gives a USER_PERMIT to the Linac4 BIC.
- Additional USER_PERMITs:
- BLMs shall assure equipment safety. But BLMs are not sensitive enough at 3 MeV, therefore no BLMs are foreseen at this energy.
    - High-loss USER_PERMIT: hardware-based; have to define damage threshold; cycle independent
    - Low-loss USER_PERMIT: cycle dependent thresholds and allowed # of bad pulses (FESA class); operator reset
        - Ruediger asks, how many integration times are foreseen for the BLMs. Christos responds that there are 4 integration times foreseen with 4 thresholds. For the High-loss the thresholds are parameters, which can be loaded.
        - Markus comments that for the slow losses a software interlock makes sense. The fast losses will be hardware based as in the LHC.
- Watch dog compares transmission between 2 BCTs:
    - High-loss USER_PERMIT: as far as possible hardware-based; cycle independent, but destination dependent (stops all cycles to a certain destination in case of single occurrence of high losses)
    - Low-loss USER_PERMIT: cycle dependent; bad pulse counter in FESA class; operator reset
- Operator switch: The operators in the CCC can inhibit the source RF.
- Vacuum valves
- External conditions: inhibit full pulses, status of different interlock zones (e.g. booster ready), BLMs in the PS for destination PS.
    - Jorg asks, how this is implemented when the transfer is at the end of the booster cycle? Bettina responds, that then the interlock is only coming in the next cycle.
- Transfer line (L4T) and Linac4 Dump Line: the bending magnets in the L4T are in series. The line has to be ready for an emergency connection after LS1.

  - Ruediger asks, if we can have an emergency switch off of the line, why not directly connecting Linac4. Bettina responds, that then the LHC beam can be delivered, but other high intensity beams may not be possible. Note: The currents provided by Linac2 are much higher.
- USER_Permits in transfer line:
  - BLMs (high-loss, low-loss)
  - Watchdog (high-loss, low-loss)
  - Vacuum
  - AQN of bending magnets.
  - Beam stopper in L4T
  - In SIS (not exhaustive): Debuncher, magnets with WICs, information on dump status, Linac4 main dump, LBE and LBS line dumps.
    - Cesare comments: The dumps can withstand continuous beam in nominal conditions (for machine protection), beam stoppers can only take one bunch (for personal safety). There is no vacuum window between the main beam dump and the line.
    - Markus wants to know what is the argument to put the beam dump request from the normal conducting magnets via SIS. Bettina answers that this was chosen to reduce the number of channels, but this decision can be re-discussed.

Discussion:

- Ruediger comments that the BIS of the Linac4 is not so different to the SPS, but it is very different to LHC.

1.2 A failure catalogue for Linac4 (A. Apollonio)

- As the realization of a failure catalogue is quite challenging it was decided to test this method with a smaller machine, like Linac4. Having such a failure catalogue can help in the design of the BIS and SIS and may ease the discovery of weak points.
- Some definitions:

- Accident: An undesired and unplanned (but not necessarily unexpected) event that results in (at least) a specified level of loss.
- Incident: An event that involves no loss (or only minor loss) but with the potential for loss under different circumstances.
- Hazard: A state or set of conditions that, together with other (worst case) conditions in the environment, will lead to an accident (loss event).
- Safety: Freedom from accidents or losses.
- Hazard Level: A combination of severity (worst potential damage in case of an accident) and likelihood of occurrence of the hazard.
- Risk: The hazard level combined with the likelihood of the hazard leading to an accident plus exposure (or duration) of the hazard.

- Technique used for this analysis is the System Theoretic Process Analysis (Hazard Analysis). Steps:
  - Define accidents.
  - Define system hazards associated with accidents
  - Translate system hazards into high-level safety requirements (constraints).
  - Build high-level control structure including the responsibilities of components and a preliminary process model
  - Refine high-level safety constraints into detailed safety requirements on for components and loss scenarios.
  - Use results to create or improve system design.
- Linac4: Accidents (MP relevant aspects):
  - Lack of beam for other accelerators (A1).
  - Damage to equipment (A2).
  - Release of radioactive material (A3).
  - Injuries to staff members (A4).
- Linac 4 Hazards:
  - The beam not sent to the TL (H1) [A1, A2].
  - The beam lost before reaching the TL (H2) [A1, A2].
  - The beam doesn't have the required quality for injection (H3) [A1].

  - Radioactive contamination of staff members (H4) [A3, A4].
  - Radioactive leaks in the environment (H5) [A3].
- Linac 4 High level safety requirements:
  - Beam must not be lost in the Linac (R1) [H1, H2].
  - Beam must have the required quality (R2) [H3].
  - Radioactive material must be surveyed (R3) [H4, H5].
  - Linac Availability must be as high as possible (R4) [H1, H2 , H3].
- This structure was refined several times. FAILURE MODES of the system have been defined, and RISKs based and failure frequency and impact were assigned to each failure mode.
- The results were summarized in the failure catalogue, which can be found on the following website: https://espace.cern.ch/linac4-and-machine-protection/SitePages/Home.aspx
- An ATS note on this failure study is currently under preparation.
- There is still important information missing for the failure catalogue, which needs input from experts.
- As an example Andrea shows an analysis performed for a male functioning of the chopper. These results of this analysis can also be found on the website. The derived failure modes need to be refined with the different system experts.
- An important application of the failure catalogue can be studies of machine availability, MTBF and MDT with Monte Carlo simulations (e.g. RAPTOR4).
- Next steps:
  - Conclude the studies related to Linac4 - Risk Assessment
  - CLIC study
  - LHC study
  - Derive Availability and Reliability models based on the Failure Catalogue

Discussion:

- **Action:** Ruediger proposes to Andrea to meet with the different colleagues to get the missing information.

- Ruediger asks who is looking into the requirement document for the Linac4 SIS. Bruno answers, that for the moment no one is doing this. Jorg comments that this was done so far by OP. Bettina responds that they are probably going to look into this beginning of 2013. Ruediger proposes to involve Andrea into this discussion. Markus comments that there must be also some hardware discussions concerning requirements, as the current SIS hardware is probably not fast enough to perform shot-by-shot interlocks.
- Markus asks, if there is any failure in Andrea's catalogue, which is so far not addressed in the BIC, SIS? Andrea answers that there is the RFQ, which currently doesn't seem to be addressed.
- Alessandra asks, why Andrea singles out vacuum and RF. Andrea responds from experience this is the frequent problem. Ruediger comments that the starting point of Andrea's study was more availability and not so much machine protection.
- Cesare comments it would be helpful to also perform an analysis how sensitive the outcome is on changing input parameters. What happens, when the inputs change by 15-20%?
- Alessandra points out that it is dangerous to say that we need an accuracy of only 5% in the quadrupoles. The specifications were 5 per mill. For machine protection 5% may be enough, but this would mean a blow up of the beam, which is not acceptable.

1.3 Beam Interlock System for Linac4, Transfer Lines & PS Booster – (B. Puccio)

- Bruno and Bettina are currently working on the detailed specifications of the BIS for Linac4 (EDMS document 1016233).
- This BIS solution is currently used in 6 machines/zones. Therefore also for Linac4 this approach was chosen.
- Interlocking Architecture for Linac4 and transfer lines:
  - 2 Master BICs (Source RF, Chopper), which get input from several slave BICs.
  - The external conditions for the Chopper Master BIC come from the normal conducting magnets (AQN magnet currents).

    - Same structure as BIC for SPS extraction line.
- Source RF Master BIC has two cases (see table slide 9):
    - Beam stopper is in the "out of beam position" or "moving", i.e. Beam_Permit is given if all other interlock conditions are fulfilled.
    - Beam stopper is in "IN Position", i.e. the source should still pulse.
- Chopper Master BIC (see truth table in slide 10): beam permit is given to three systems
    - Action on Pre-chopper
    - Action on Chopper
    - PSB-RF is disabled
        - Jorg asks if in normal beam conditions the beam permit will be always "true" or pulsing. Bettina comments that the beam permit will change during the cycle for most systems while only a few systems will be always true. Jorg comments that the slow monitoring systems will therefore not be applicable, as they will not get the status of the system at the right time. Markus comments that on the BIS side a supervision GUI with the needed time resolution for pulsed machines is already in work.
- Bruno shows a matrix of the connection of the different user systems to the BICs (Master / Slave) (slide 12).
    - Markus asks, which of the inputs are mask able and which un-mask able. Bruno responds: Mask able in the transfer line: low loss watchdog and vacuum valve. Ruediger comments that the mask able channels only can be used with the check of safe beam parameters. **Action: Offline discussion.**
    - Bernd asks, how the signal from the dump is generated. Cesare answers that there are different sensors in the dump. The output of these is combined into an analogue signal and a switch (for redundancy). E.g. in the absence of cooling a signal is created to cause an interlock. Note, the material of the dump is graphite with stainless steel jacket and water-cooling.

- BIS Interfaces (slide 15): For Linac4 it is proposed to use the Beam permits signals as flags on copper cables (LHC fiber, due to long distances). Differential transmission of the signal guarantees the supervision of the target system. It is proposed to use the CIBIT boards installed into BIC crates. The target systems are advised to use CIBIR boards, but could also use a different board with the same logic.
  - Ruediger comments that the logic is still active high, i.e. if a signal is lost, the beam permit is removed.
- A detailed description of the beam permit interface for Linac4 can be found in the EDMS document 1235601.
- Bruno shows the Linac4 Master Plan (schedule, slide 21).
  - Alessandra comments that the plan is diluted and delayed due to the delay of LS1.
- Status of the BIS deployment:
  - BIS for 3MeV test stand is fully installed and almost ready for commissioning.
  - For additional tests a dedicated BIC will be deployed in the Booster during the next TS.
  - Materials specific for Linac4 are ordered and under production (VME crates, BIC boards, CIBU units).
  - Monitoring software and java application are already available. The adaptation to fast cycling machines and specific displays is ongoing.
  - Most cables have been ordered, for some cases the location has not been provided by the User_Systems.
    - Alessandra asks, which cases are meant. Christoph responds that there are 10 cases, e.g. the cables from the power converters / bending magnets.
- BIS is installed in the 3 MeV test stand. This is a good test bed to learn, although several specificities of this installation will not be adopted in Linac4. A new display was provided by Markus' section to have a cycle view (see screenshot in slide 26).

  - Ruediger asks if this view shows the status due to timing signals. Yes, that is the case.
- Outstanding issues:
  - Cables: (see above).
  - BLM connections: for the Linac4 and TL zones, 8 diff. signals are expected, but only two can be provided by the BLM crate. Discussions are ongoing.
    - Bettina comments that the High_loss interlock will block all the lines.
    - Markus asks if this signal is latched, or if it would be overwritten in the next pulse. Christos answers that the hardware interlock is latched until the user resets it.
    - The interlock behavior in different Users needs to be addressed offline.
  - Beam line destination (power converters interface for current measurements to deduce and interlock on beam destination).
    - Markus comments that there is a comparable system already in use by EPC (North zone) that allows for dependable current measurements.
  - Signal from dumps: implementation details not know, but an EDMS document with specifications is expected.
  - Software interlocks: Who will take care of this? OP?
- The BIS layout has been defined for a complete Linac4 installation. However the commissioning will take place in phases. Therefore different parts of the BIS need to be mask able in this period. In addition the User_systems must be able to adapt to the commissioning state of the BIS. Furthermore some systems (e.g. emittance measurements) will only be operating during the commissioning. These constraints need to be discussed and specified in detail later.

Discussion:

- Andrzej asks if the current BIS installation for the 3MeV test stand is final. Bruno answers that this is only a temporary solution and will be changed when the test stand is moved.
- Jorg asks, if there is an access bit foreseen for the Linac4 BIC? Bruno answers that this is not foreseen. Bettina replies that this is realized at the level of the slave systems (bending magnets, choppers, …).
- Andrzej wants to know if there is a global architecture foreseen for the BIS, as the PSB will have to be added in the (near) future? Linac3 and PS could maybe also be interested in the future? Bruno answers however that these installations will not be connected in a Master-Slave architecture with the LINAC4, but rather be independent systems with a user permit transmitted upstream (like done from the LHC to the SPS extraction).
- Jorg asks if the CIBUs were produced newly or from stock? Bruno answers that 80 CIBUs were produced, but they are exactly the same as the old ones.
- **Action:** Markus comments that a next step would be to finalize the BIS specifications.

1.4 Miscellaneous

- Markus explains that the B2 BSRT mechanism and mirror were taken out this week. B1 is in parking position. Thus, there is currently no monitoring of the abort gap. At the moment there are different alternatives investigated (LHCb, Alice, IR3 Collimators, Diamonds, …). A meeting will be organized before the Jeune Genevois to decide how to operate without the BSRT before TS3.
- Richard asks what the probability is to have the BSRT back after TS3. Federico comments that there is a strong push to propose an optimized design and repair the BSRT during TS3. Jorg comments that the BSRT is an important monitoring tool and therefore needed during the upcoming 25ns operation.