82nd 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 Machine Protection and required availability in view of the HL-LHC goals – (D. Wollmann)

- Daniel shows the plot for the energy stored in the beam vs. momentum for various accelerators and reminds on challenges concerning MP for HL-LHC:
    - Re-evaluation of the LHC damage studies taking into account HL-LHC beam parameters.
    - Study new failure scenarios (due to optic changes and new equipment such as crab-cavities,..).
    - Balance between protection and machine availability.
- Assumptions for LHC MP Systems: time between the occurrence of danger to the machine and the beam dump. This time includes detection of the problem, communication, synchronization and abort of the beam. Typical time is 320us (max) < t < 10ms, depending on the type of failure and detection system:
    - Ultrafast failures (single-turn).
    - Fast failures (<few ms).
    - Slow failures (>few ms).
- The expected differences in failure scenarios for HL-LHC and the upgrade needed:
    - Ultrafast:

        - Work ongoing in the different equipment groups for the replacement / upgrade of passive protection devices (Injection Protection, Dump Protection, Ring Collimators) to HL-LHC beam parameters.
        - In case of missing BB kick after dump of one beam: 0.9-1.1σ single turn orbit perturbation is expected (HL-LHC).
        - Instantaneous drop of the deflecting voltage in a single Crab Cavity (CC): simulations predict orbit distortion (modulated by betatron tune) of 1.5σ within the 1st turn and respective loss of energy. Thus up to 2MJ of beam impacting on collimators (assuming overpopulated tails), which is above damage limit of current collimators.
    - Fast: failures will happen 25% faster because of higher β-function. The detection time of the failures (40÷100us) is sufficient for HL-LHC optics, therefore there's no need for Machine Protection to replace D1 by superconducting magnet.
        - Markus comments that in current HL-LHC baseline D1 is superconducting, hence this failure case will by far not be as critical anymore.
        - Jörg comments that the impact on the orbit correctors around D1 should be checked. UFOs are already an issue.
    - Slow: not expected to be a challenge for HL-LHC MP, but might be an issue for machine availability.
- Possible strategies for mitigation of the damage due to the Crab Cavity failures:
    - Increase the number of cavities to decrease their individual voltage/kick. However the new crab-kissing scheme proposes to have 4 CC (distributed in both planes) with max voltages up to 6.6 MV (instead of 3.3 MV) which might provide a kick with double the expected strength.
    - Very fast LLRF control.
    - Partial depletion of halo.

    - Disadvantage is in reduced detection time of the failure and also lost redundancy in BLMs.
    - High reliability methods for monitoring and interlocking of halo population are required.
- The tests of CC are ongoing or in preparation, and one aim is to confirm the worst case voltage and phase failures. Depletion methods have to be shown to work efficiently.
    - Markus comments that the baseline for the CC is still 3.5 MV. Total voltage needed to close the orbit bumps is 12.5 MV. Baseline scheme has been recently modified to 4 modules/beam/IP side/ Three crab-cavity types are currently tested in SM18.
- Expected availability of HL-LHC as well as the impact of the UFOs, SEUs, BLM thresholds, machine failures and average fault times on the yearly integrated luminosity is estimated by using Monte Carlo simulations. Daniel shows a chart of the lost fill time and fault time for different LHC systems (presented in Evian2012 by B. Todd).
- Model assumptions are taken from 2012 data. Thousand years of operation are simulated. As input to the mode, the fault distribution has been modelled with 4 scenarios: short failures (0-1 h), failures requiring access (1-4 h), cryo/failures requiring multiple accesses (4-12 h), and long failures (>12 h).
- According to the Monte Carlo simulations with 2012 initial conditions, the expected average integrated luminosity per year is 213 fb^{-1}. When the expected increase of the UFO rate is taken into account (100 UFO dumps at 7 TeV with current BLM thresholds), the luminosity drops by 15%, to 179 fb^{-1}. With SEU mitigation (number of dumps going from 50 to 20 after LS1) the luminosity is estimated to be 220.5 fb^{-1}.
    - Anton asks if the redistributed BLMs are taken into account while calculating the UFO dumps.
    - Andrea says that the simulations are done for the current setup and thresholds.

    - Daniel says that if the BLM thresholds are increased by factor 3, the number of UFO dumps drops linearly with the thresholds – down to 33 UFO dumps instead of 100 (in 66 cases one would register a UFO without dumping).
    - Bernd comments that the new distribution of BLMs does not make a difference for the protection levels required.
- Daniel presented a table with expected luminosities at different assumptions and failure/mitigation scenarios, and a plot of the integrated luminosity vs. average fault time and the machine failure rate (which shows the fraction of the fills dumped by failure). To increase the integrated luminosity per year, the average fault time and/or the machine failure rate needs to be reduced.
- Future activities on MP for HL-LHC: Functional requirements for BIS2 are being developed, QPS for new triplet magnets and sc links is being developed, final definition of the HL-LHC beam parameter envelope is very important, measurements of the beam distribution at 6.5/7 TeV (tail population).

Discussion:

- Jan asks if the functional requirements for BIS2 are different from BIS1.
- Markus answers that they potentially could be different to accommodate for crab-cavities and other new HL-LHC equipment. However until LS3 or HL-LHC upgrade, the BIS1 specifications are still valid.
- Jan comments that there are two types of failure modes in the machine: acceptable and unacceptable. With the upgrade of the old equipment the specifications for acceptable failure modes could change, but unacceptable failure modes will always stay the same.
- Jörg comments that increasing the number of CCs helps, but it could not mitigate all the possible failures.

- Markus says that the requirements for BIS2 will be established soon, because the upgrade is planned for LS2 or LS3.

1.2 SixTrack studies for Crab Cavity Failures in HL-LHC (B. Yee)

- Bruce reminds us on the beam optics parameters of the HL-LHC and the functions of the Crab Cavities (CC).
- The SixTrack for collimation was used to evaluate the beam losses produced by the CCs failures. The studies were done for CC with ~400 MHz and 3.5-3.8 MV.
  - The study focused on the losses in the horizontal plane (IP5), therefore the CCs at IP1 were switched off in all the simulations.
  - The maximal displacement was found to be $1.6\sigma_x$ at $2.4\sigma_z$ (position in bunch) for voltage and $2.2\sigma_x$ at $0\sigma_z$ for phase failures.
- Losses in the collimators and in the aperture for two kinds of halo distributions were studies:
  - Tiny halo (hor. halo at different position with a smear of 0.1σ and complete vertical and longitudinal beam distributions):
    - The percentage of the beam absorbed in the collimators during Phase Failures, Voltage Failures and Normal Operation varies between ~10^{-4} % and ~80 % for different halo positions (the closer the halo is the fewer particles are lost in the collimators).
    - The percentage of the beam lost in the aperture varies between ~10^{-4} % and ~1 % depending on the halo position for different cases (PF, VF, NO).
  - Thick halo (hor. and vert. halo with different smears and with a complete beam distribution in the longitudinal phase space) – 4 different distributions.
    - The impacting energy depends on the duration of the failure. The location (aperture/collimators) and the amount of the lost particles depend on the type of the failure. Among all the studied cases and beam distributions, the

maximum percentage of the beam lost in the aperture was ~$32x10^{-5}$ %, and in the collimators ~1.5%.

- Tracking to reach the steady state (the change of the voltage as well as of the phase with turns was taken into account). The histogram of the particles lost in the collimators at different turns is shown. Most of the particles are absorbed at TCP.C6L7.B1 (hor. primary collimator).
- Global inefficiency (the number of the particles lost in the aperture divided by the total losses in the collimators and aperture) for all the different cases and failure scenarios is calculated to be between $1.7 \cdot 10^{-4}$ and $4.8 \cdot 10^{-4}$. The global inefficiency for normal LHC performance is $3 \cdot 10^{-4}$, therefore CCs do not seem to increase the global inefficiency significantly.
    - Markus comments that this seems to indicate that the speed of the failure does not influence the inefficiency (as impact parameter mostly constant).
    - Anton adds that this ratio depends on the impact distribution. The energy deposition in the arc is higher if there is a lot of impact on the primary collimators. The phase advance is such that the primary collimators are the first ones that are hit.
    - Daniel says that secondary collimators cover the phase space much better than the primary ones in the nominal case. In IR6 there are secondary losses.
- Mitigation strategies and results: drop the voltage to zero in several turns.
    - Linear drop: beam is reduced by ~71% in 9 turns.
    - Exponential drop: beam is reduced by ~65% in 9 turns.
- The FLUKA calculations of the peak energy density in the coils are needed to assess if these failures will induce magnet quenches.

Discussion:

- Markus comments that the studies were done in 3 different ways and the results are matching the previous studies. Now experimental validation of the worst case failure scenarios is needed as well as measurements of beam halo with 25ns. With this new input & latest optics the tracking studies have to be reiterated.

1.3 UPS powering tests – (I. Romera)

- Markus states that the UPS powering tests need to be performed before the restart of the Machine.
- Ivan reminds us, that the MP systems depend vitally on redundant powering. UPS power was reconfigured; the F4 line was introduced (mainly for the new QPS system) after the 2008 incident.
- Why do we have to do that:
    - Verify that single protection systems have redundant power supplies.
    - Verify correct powering path.
    - Verify that MPS is operational even in case of a power cut
    - Identify interdependencies between different systems
    - Verify that magnet powering is stopped in degraded powering conditions
    - Check impact on other, not redundantly powered systems.
- There are currently 64 UPS systems installed in the LHC. While in the Alcoves and odd points one individual UPS powers the F3 and F4 line, the even points feature two UPS parallel-redundant systems. Backup time defined by the QPS is 10 min.
- During LS1 all UPS will be replaced and in addition also the UPS configuration in the alcoves and Odd points will be changed, to guarantee that in case of one failure in a UPS the connected systems remain powered. The UPS in the UA and US zones will be completely renovated (but architecture remains unchanged).
- Ivan shows the results of the UPS powering test in 2012:
    - Tests were performed point by point in two adjacent sectors.
    - Stop of the UPS system.
    - No major problems were observed, however small but important problems were revealed: Some QPS, BLM grades were not powered correctly from the UPS but from the mains.

- Proposed test procedure of redundant UPS powering:
  - IT star-point will be transferred to a temporary power supply (normally UPS F3).
  - Switch of switch board downstream on UPS F4.
  - Verify if MPS systems are still powered.
  - The users without redundant powering see the impact.
  - Optional in UA63/67: Cut 2nd time EOD F4 to verify LBDS functionality.
  - EOD F3 downstream the UPS F3 is powered again.
  - The IT star-point rack is transferred back to its initial power supply coming from the UPS F3.
- Tests in odd points/RE alcoves:
  - New configuration with 3 UPS systems and 2 redundant power paths F3/F4.
  - Repeat the described tests 24 times.
  - TBD if surface UPS should be tested as well.
- The tests will take 1/2 per odd point/alcove and 1 day per even point. Planning: after AUG tests, from middle of April till end of July at all the IRs.
- Next steps:
  - Finalize survey from all relevant users.
  - Integrate into official planning.
  - Prepare and circulate procedure describing test and preparations.

Discussion:

- Markus comments: Clearly tests should be performed du assure dependable operation of MPS systems before startup, but it is important to find the correct time slot, as systems need to be ready but still not to cause too much impact on e.g. cryogenics. Cryogenics can easily take 2-3 days for recovery from these tests. This needs to be discussed with all the interested teams.

1.4 Miscellaneous

- **Action:** BSRA levels: Jan will write the updated proposal into a note and distribute it.

- Exotic scrubbing beam with 5 ns bunch spacing: Jörg received the information from RF that they would prefer to do the split of bunches in the LHC (inject into unstable phase and re-capture into two buckets instead of splitting the beams in the SPS). To be discussed in the LBOC.
- Verena comments that the gain to do the splitting in the LHC will maybe less efficient than in the SPS. All the effects (damper, uncaptured beam, beam diagnostics, etc.) need to carefully studied WITH beam tests.