FAIR Commissioning & Control Working Group

Notes from the meeting held on 18th November 2015

e-mail distribution: FAIR-C2WG-ALL at GSI.de, participants list

Agenda:

- Accelerator & Beam Modes – Feedback on circulated Specification (jump below), FC²WG-all
- Experience with LHC Beam Loss Monitors and Lessons for FAIR (jump below), Mariusz Sapinski
- FLUKA Study of Beam Loss Monitors for the SIS100 at FAIR/GSI: General Diagnostics and Quench Prevention of Superconducting Magnets (jump below), Sanja Damjanovic

1. Accelerator & Beam Modes – Feedback on circulated Specification, FC²WG-all

R. Steinhagen summarises the key-concepts of the 'Accelerator & Beam Modes' technical concept that has been circulated for comments and that will now be circulated (via EDMS) for approval by the MPLs and key-stakeholders (affected technical groups) (see slides and specification details):

The main purpose of formal accelerator and beam modes are

- to communicate the intended accelerator operation to the experiments and wider FAIR community, and
- to condition the various control sub-system responses (e.g. archiving, interlock and fast beam-abort systems, management of critical settings, etc.).

It shall be noted that, besides formalising their names, these modes are not a new concept but already being practised during normal operation at GSI and accounted for in the annual beam schedules (aka. “Strahlzeitplan”) and electronic log-books. What is new is that the new control system for FAIR will be made aware of these modes which in turn opens the possibility to derive automated rules, automated statistics and other features from these modes.

The proposed 'modes' (deliberate user-driven states (references or 'desired target') that follow and track the normal operational sequences) and 'actual states' (actual measured state of the accelerator or beam) provide the possibility to define associated rules depending on the specific phase of operation. While the specification defines a common base of modes, state-diagrams and some transition rules between these states, most rule details need to be defined elsewhere, since these are often specific for a given machine, transfer-line segment or experiment.

The mode changes will be initially tracked by operators and subsequently by semi-automated sequencer.

Discussion:

G. Franchetti asked whether the specification is only applicable for the initial commissioning.

R. Steinhagen and R. Bär clarified that the beam mode state diagram and sequence of 'no beam', 'pilot beam', 'adjust' etc. would equally cover initial commissioning, the annual re-commissioning, and regular machine operation (e.g. after a mode of operation changes). The system of states and derived rules will be fundamental to FAIR operation and control, and thus will be always present. However, the specific rules need to be defined at a later stage.

G. Franchetti worries about being too constrained by the beam modes and asked for some rule examples. R. Steinhagen elaborates that there are operational scenarios where restrictions are needed in order to protect the machine from potentially 'dangerous' setting changes when, for example, high-intensity beam is circulating in the machine. For example, some settings changes shouldn't be done with 'stable beams' while experiments are taking data or have their sensitive detectors moved close to the beam. In this cases, the settings changes would either be reduced to zero or limited to a specified safe window. D. Ondreka and R. Steinhagen highlighted that such a mode-dependent setting protection would minimise triggering hardware based interlocks or unnecessary reduction of beam availability. These rules could be configured in such way, that machine development experiments (with low/'safe' beam intensities) should not suffer from them.

S. Pietri commented that this approach appears to be sensible for synchrotrons but wonders whether this would be equally applicable to HEBT or the Super-FRS experiment. In particular for Super-FRS, the dangerous scenarios (aside from the Super-FRS target) are less for high-intensity beams but rather with lower intensities when the sensitive detector equipment is moved close to the beam. R. Steinhagen stressed that the given state machines and associated rule sets are specific for the given machine, transfer-line or experiment. Super-FRS may opt for a different rule-set if required.

S. Petri commented that the discussed Setup-Beam-Flag (SBF) limits are different (and probably much lower) for Super-FRS. R. Steinhagen explained that the SBF definition depends on the given machine and is used mainly as part of the machine protection concept for the primary beams (N.B. SBF allows to mask less critical interlocks for low-intensity/'safe' beam during machine set-up). The SBF is used for fast hardware interlocks, but similar rules could equally be derived from the beam modes if the time scales are slower or less critical.

2. Experience with LHC Beam Loss Monitors and Lessons for FAIR, Mariusz Sapinski

In his presentation (see slides), Mariusz Sapinski provided an overview and experience with the LHC Beam Loss Monitoring System (BLM). The main purpose of this system is to actively protect the machine against damage and to prevent quenches that would otherwise unnecessarily minimise the machine availability. The BLM interweave into the general LHC machine protection concept and provide after the passive components (protecting the machine against ultra-fast losses) also an active second 'safety net' for fast losses and failure scenarios on the scale of a few turns to hundreds of seconds.

He summarised the most important BLM system specification requirements (see slides p . 8):

- Sensitivity: 5% of quench level
- Dynamic range: about 105 for signal integration time 50 us
- Response time < 1 turn (0.1 ms)
- Failure rate (reliability): SIL1 (specified) and SIL3 (achieved).

Reliability has been an important requirement underpinning the overall LHC BLM design. The initial BLM specification required a system failure of less than once per month which corresponds to a failure rate of any individual BLM of about once in 10 years, or a safety-integrity-level rating of 'SIL1' (see IEC 61508 for details).

Due to the redundant design and procedural verification of the 'as good as new' system functionality the actual LHC BLM system could achieve a SIL3 performance (1 critical failure in about 10000 years). Part of these 'sanity checks' are executed once per fill and include connectivity checks monitoring the BLM signal's dark-current modulation in response to programmed high-voltage supply modulations (detailed reference: J. Emery et al., Journal of Instrumentation, Vol. 5, C12044, 2010), and internal beam permit checks that verify the ability of every threshold comparator to send beam dump requests.

The original detector choice was to used ionisation chambers (ICs) for areas with expected beam losses, based on earlier good experience with similar chambers at the CERN-SPS, and secondary emission monitors (SEMs) for high-radiation areas (e.g. in areas with collimators).

Experience with beam showed that the SEM did not work as well as hoped for and were thus later modified to ICs with very low gas pressures in the cell. Also initial BLM design loss scenarios where particles are first lost in places with a large β-function and/or dispersion (mainly quadrupoles and dispersion suppressor) turned out to be irrelevant during Run I due to the good orbit control around these devices. Thus every every 3$^{rd\ BLM}$ detector was moved to another location to better cover losses due UFO (Unidentified Falling Objects) that became the more dominant loss scenario during Run I.

In the LHC most of the initially thresholds were driven by the aim of preventing quenches based on previous experience with other superconducting hadron collides: while for HERA this requirement was not important, experience with Tevatron has shown that quenches may have significant impact (Tevatron: long p-bar accumulation times → LHC: long recovery & filling time) on the machine and beam availability. What came at a nice surprise was that LHC initially showed almost no quenches with beam due to the good orbit stability and large quench margin (at 4 TeV).

M. Sapinski highlighted that the thresholds are essentially grouped into three groups: ultra-fast losses on the time-scale of few 10 us to ms where thresholds are dominated by the cable enthalpy, fast losses on the time-scale of a few ms to seconds where thresholds are defined by the heat-transfer and enthalpy of the liquid helium bath surrounding the cables, and slow losses that are limited by the cooling power of the cryogenic system. For warm magnets the thresholds are derived from the requirement that the material should not be damaged for fast losses or overheated (about 100 °C) for slow losses.

New recent developments include the use of smaller ionisation chambers and with lower gas pressures to lower the sensitivity (re-purposed SEMs for collimators), cryogenic BLMs that measure the losses closer to the superconducting magnet coils, and fast diamond detectors that permit a bunch-by-bunch diagnostics. N.B. There will be a ADAMS workshop at GSI held on that topic between 3rd and 4th of December at GSI.

Overall, BLMs played a critical role for the LHC machine safety and beam diagnostics. Despite their complexity, they proved to be very reliably showing no spurious (i.e. false-positive) beam dumps. Based on his experience at LHC, M. Sapinski expressed some recommendations and highlights to be taken into account for the use of BLMs at FAIR:

- Complex data definition and flow
- Some loss scenarios turned out irrelevant (but we would not know it without BLM system).
- Unexpected loss scenarios appeared.

Discussion:

C. Omet asked whether the LHC BLM design criteria requiring a sensitivity of 5% w.r.t. the estimated quench threshold was difficult to achieve under real-world conditions. M. Sapinski confirmed that the achieved sensitivity was actually much better than 1%, and in some cases even better than 1‰ w.r.t. the quench thresholds.

C. Omet further asked whether the energy dependence for the quench thresholds were calculated or experimentally verified and how many quenches have been produced artificially. M. Sapinski explained that the initial thresholds where based on model calculation, and only later validated through a few dedicated beam experiments. Less than 20 quenches occurred during the first three years of LHC operation (run-I), out of which 70% were due to quench tests. The other quenches were caused due to operational mistakes at injection (showing example with quenches at injection, current for MQ magnets was not at injection level, beam lost).

S. Damjanovic commented that the statistic also shows that the recovery time is too high to allow more quenches. R. Steinhagen also commented that for LHC single event upsets (SEUs) due to secondary showers were more critical during that phase (rather than quenching magnets) as these latched main power supplies in areas that have been previously considered to be less prone to SEU. D. Ondreka commented that this type of failure will be less critical for SIS100 (different tunnel geometry, more shielding). C. Omet cautioned that all quench detection electronics will be shielded in the supply tunnel and about 12 meters away from the primary loss sources. For the BPM electronics there is only one meter of concrete. He added that experience with beam will be the mark of how SEU may affect SIS100 operation.

D. Ondreka asked how the performance of the simulations compared to the actual quench tests. M. Sapinski affirmed that these were quite good and differed only by about a factor 2. There were however also tests that are not yet fully understood and where the discrepancies are larger.

D. Ondreka asked about the initial threshold margins. M. Sapinski replied that the specification prescribed initial settings to within a factor 5 of the quench level and that a factor 3 should be targeted after some experiments validating the exact quench thresholds. Initially these thresholds were sufficient but lower thresholds are more complicated for different loss types and loss durations. At least for fast losses at injection these thresholds discrepancy were quite small. LHC operates presently (run-II) quite close to the actual quench limit in some locations. Some of the thresholds are already 20% above the initially calculated quench thresholds, and are further pushed. It is hard to assess whether the thresholds are not already over the quenches. No quench tests have been performed on particular magnets. There are still a lot of unknowns left.

3. FLUKA Study of Beam Loss Monitors for the SIS100 at FAIR/GSI: General Diagnostics and Quench Prevention of Superconducting Magnets, Sanja Damjanovic

In her presentations (see slides), Sanja Damjanovic summarised her simulation results regarding the to be expected BLM sensitivities and their potential use-case to prevent beam induced quenches in SIS100.

She compared two analysis procedures: a) based on the individual particle tracking described in detail in LHC-Project-Note-422 (2009) and CERN-EN-NOTE-2010-001, and b) the method based on the energy deposited in the acvtive BLM volume and applying a generic conversion factor for creating electron-ion pair. S. Damjanovic has shown that both methods yield the same results, but that the preferably used the second method as this provided a better statistic than the individual particle tracking and energy folding method.

The possible or to be expected BLM sensitivities have been studied on the basis of the anticipated nominal beam losses on the SIS100's electro-static septum wires. In the simulation, the virtual (test) BLMs were placed around (± 2 m) around the electro-static septum on either side of the beam pipe with the largest signals occurring at the radiation-resistant warm quadrupoles. Assuming a lower BLM detection threshold of 10 pA, her analysis showed that the LHC ionisation chamber (IC) type BLMs should be sensitive enough to resolve 0.1% losses at injection energy (0.2 GeV/u), and 10^{-6} of nominal U^{28+} beam intensities being lost at 2.7 GeV/u assuming the target U^{28+} beam intensities for FAIR (N.B. the nominal losses on the septa wires are expected to be on the few percent level).

In the second part of her presentation, S. Damjanovic focused on the possible use of the BLMs to prevent beam-based damages to the machine and quenches of the SIS100 superconducting magnets. She pointed out that the SIS-100 beam parameter at extraction are at the damage limit for metallic structures in case of perpendicular beam loss.

For the quench prevention scenario she focused on two loss scenarios: energy deposition from ions hitting the cryo-absorber (U^{29+}, source I), and energy deposition from ions hitting the upstream de-focusing quadrupole chamber ($U^{>30+}$, source II).

The FLUKA simulation indicated that the highest energy depositions and highest signal levels are to be expected in the steerer module down-stream of the cryo-absorber which would thus also be a prime location for BLMs. Her analysis indicated that for the studied loss scenario, that there is only an insignificant left-right asymmetry of the losses outside the cryostat. Interestingly, the signals at quench are almost identical for various ion species and various extraction energies, including protons (factor 2 below). S. Damjanovic attributes this to the fact that underlying mechanism ('energy required to quench' vs. 'energy deposited in the material') depends mainly on the total available energy of the beam.

For the specific studied case of U^{28+} losses at 2.7 GeV/u the estimated quench threshold around $2.2 \cdot 10^{11}$ ions/s being lost on the cryo-absorber, which is about an order of magnitude higher than the worst-case peak charge-state losses assumed in previous analyses to be lost on a single cryo-absorber (StrahlSim results, Lars Bozyk et al. 01/2013). The quench signal would reach currents of about 4 uA (2 uA for protons) in the BLMs which are well above their resolution limit (10 pA). Thus, the LHC-type IC could be used for quench prevention, although one would need to loose very large fraction of beam in order to quench.

S. Damjanovic summarises the main results of her analysis:

- LHC-IC type BLMs are estimated to be very sensitive to the beam losses expected from charge exchange of U28+ beams.
- Quench-prevention thresholds appear to be almost identical for all considered ion species and beam energies.
- Quench-prevention thresholds appear to be independent of beam loss rates.
- Two different longitudinal BLM positions per quadrupole could be foreseen to help distinguish charge-exchange from other beam losses based on the loss topology.

Discussion:

R. Steinhagen asked whether one could assume the same 10 pA noise level indicated for the LHC BLMs also for the FAIR specific BLM implementation (same IC, but different current-to-frequency converter electronics, cabling etc.). M. Sapinski replied that the 10 pA at LHC would come from injection. The 10 pA is the bias current that is injected all the time in order to ensure that the integrator circuit is alive.

D. Ondreka asked about the maximum dynamic range for given beam intensity. A. Reiter and P. Boutchakov replied that the proposed current-to-frequency converter has an effective range of at least 10^5. For the highest gain a minimum conversion rate of 100 fC/count and a linear count rate of 1 MHz (max. being 2 MHz) is given. The gain ranges can be set between 100 nA, 1 uA, and 10 uA. A lower noise floor below 10 pA seems to be possible but would require very good grounding. R. Steinhagen commented that this design estimate would correspond to a sensitivity of the system roughly a factor 10 better than estimated in the presentation.

C. Omet commented that the energy deposition of 2 kJ/g mentioned in the 'machine protection' summary (see slides p.13) would be inaccurate since the beam size is not symmetrical in both planes. He estimates that while the SIS100 beam energies and nominal U^{28+} intensities are above or at the limit to melt steel, that this would be only true if these beam profiles are not smeared-out. He expects that in most cases when the beam is lost in an accelerator, that one would get a very shallow and not perpendicular impact angle. S. Damjanovic replied that this would not change the results in principle. Furthermore, he stated that the BLMs are currently not foreseen as 'quench prevention' detectors, the main reasons for using them will be machine protection, observation of beam losses for settings optimization and reduction of activation (HOM).

D. Ondreka highlighted that for fast extraction and two of the kickers failing (rare double failure), the beam is shot between the beam pipe and the extraction channel and would hit the beam pipe perpendicular. R. Steinhagen recalls that this double failure is estimated to occur about once per year (correct: 0.6 times per year). D. Ondreka commented that the rate and consequence of this type of failure is too severe to not take the given precautions (N.B. this failure is already being looked into).

G. Franchetti asked whether it is understood why the quench protection thresholds are the same for the different ion species, energies and even for protons. S. Damjanovic explained that her understanding is that the prediction are connected to the total beam energy.

C. Omet commented that extensive studies have been performed for the emergency dump system. For SIS100 a current measurement on the cryo-absorber is planned that could be treated similar to the BLMS and indicate charge-exchange losses as done in SIS18. Detailed optic studies are still pending for some cases in order to see where we have really damage potential for perpendicular impacts. For a single injection C. Omet estimates that SIS100 should be almost safe as one cannot destroy anything with a single SIS18 shot. At extraction energy the situation is more critical as the beam size is lower and the intensity and energy much larger.

D. Ondreka mentioned that fast losses of $1.3 \cdot 10^{11}$ protons on a cryo-absorber would quench down-stream magnets. S. Damjanovic continued that the BLM signals could also be used to prevent the electro-static septum wires from melting. C. Omet commented that this is already being considered and presently under review by the SIS100 MPL (P. Spiller).

The next meeting is planned for: Wednesday 2nd December 2015, 15:00-17:00 (SE 1.124c)

Reported by M. Sapinski, Ch. Hillbricht, R. J. Steinhagen