# FAIR Commissioning & Control Working Group

## Notes from the meeting held on 7th October 2015

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

Agenda:

- FAIR Transmission Monitoring and Performance Optimisation (jump below), Ralph J. Steinhagen

### 1. FAIR Transmission Monitoring and Performance Optimisation, R. J. Steinhagen

In his presentation (see slides for details), R. Steinhagen presented some preliminary ideas related to the FAIR transmission and performance optimisation and related Beam Transmission Monitoring System (BTM). Due to precent-level measurement dependencies of the beam transformer and the requirement to control particle losses well below the percent level, R. Steinhagen proposes to include also beam loss monitors (BLMs) and the available radiation monitors (personnel protection) as standard input to the BTM concept.

The purpose of the BTM System is to provide a facility wide surveillance of bunch, batch and beam intensities in order to evaluate the injection-, ramp-, fast- & slow-extraction (in-)efficiencies and – if out of tolerance – to suppress further injections or the extraction to the sub-sequent accelerator chain. The process can be broken down into smaller checks that are daisy-chained according to the given beam-production-chain across the facility.

The main goals of the BTM are:

- Optimisation of beam-on-target figures
- Minimisation of machine activation (ALARA principle: 'As Low As Reasonably Achievable')
- Minimising the risk of combine machine protection failures

In case of poor transmission performance, the BTM could be used to inhibition further injections into the ring using the timing system, suppress the extraction to the subsequent accelerator or transfer-line, or possibly even triggering a fast-beam-abort. However, the latter – typically intended to protect against fast machine failures – may be too stringent as default measure for poor transmission performance.
R. Steinhagen grouped the different possible BTM monitoring rules into four groups:

1. multi-turn injection/accumulation optimisation
2. losses during the cycle (due to RF capture, ramp, transition crossing, space-charge or other beam related instabilities)
3. losses during fast extractions
4. losses during slow extraction

These rules compare the particle intensities as measured by the beam transformers in the transfer-line prior, inside the ring, or transfer-line leaving the given accelerator.
The required accuracy, resolution and robustness of the involved beam instrumentation depends much on the amount of 'acceptable losses' inside the accelerators. One needs to accept a certain

amount of losses due to operating the FAIR accelerators close to the space-charge limit, Touschek scattering, finite machine acceptance and aperture, finite vacuum and rest-gas interactions, optics errors, beta-beat, dynamic aperture, and other fundamental real-world limitations.

Most particle losses in SIS100 are mitigated by dedicated beam halo cleaning system that intercept the beam and converts the otherwise uncontrolled losses into controlled losses on this purpose specifically designed collimators and cryo-absorbers.

Besides machine transmission performance and hard machine protection (i.e. material damage) considerations due to fast losses (further discussed in an upcoming FC2WG meeting), machine activation and resulting machine hands-on maintenance provides another limit on how much particles can be lost.

As a working hypothesis, the highest tolerable losses for accelerator operation is often quoted as the '1 W/m loss criteria' for protons (see also: N.V. Mokhov and W. Chou, The 7th ICFA Mini-workshop on High Intensity High Brightness Hadron Beams, USA, 1999). Based on an earlier presentation given by I. Strasik ("Tolerable Beam Losses in SIS100", at the HIC4FAIR workshop, Hamburg, 2015), these '1 W/m loss criteria' as been re-validated by I. Strasik using FLUKA. These losses relate to an activation dose of about 1 mSv/h at 30 cm after an irradiation time of 100 days and 4 hours of cooling time. Due to the different nature of interactions with matter, the '1 W/m loss criteria' is higher for ions for the same energy per nucleon (scales roughly with the nuclear number, ie. U 'W/m' losses can be a factor 238 higher than for protons to result in the same activation level).

Including the presently estimated collimation efficiencies and assuming that no other elements than collimators may reach above '1 mSv/h activation' criteria, the maximum tolerable losses would be about 5% for protons or 10% for $^{238}U^{92+}$ ions at SIS100 extraction energies. R. Steinhagen cautions that these numbers are only indicative and that the existing operation, shielding and radiation permit (aka. "Strahlenschutzverordnung und Betriebserlaubnis") limits these to below 3% for 29 GeV protons. R. Steinhagen stresses that normal operation should aim at losses that are significantly below these limits (↔ ALARA principle). For comparison: the CERN-PS accelerator achieves routinely about 4-8% cycle losses (covering injection & extraction) for similar intensities (data courtesy R. Steerenberg, 19th March 2012).

On the question of how 'low' is 'reasonable', R. Steinhagen stated it would be unrealistic to assume zero losses for ion operation (see: above loss mechanism) and that one may need to accept a certain amount of losses by design for FAIR. Nevertheless, in this context of unavoidable losses, he proposed that we would need to agree to a 'golden standard' of exhausting reasonable common operation practises of controlling beam parameter known to induce particle loss before declaring these losses as 'acceptable'. The proposed steps to be performed and optimised for low-intensity beams before going into stable beams production include:

- Extraction/Injection Matching
  - first-turn trajectory steering (BPMs),
  - energy matching (BPMs & Schottky),
  - coarse collimation (IPMs) (removing excessive tails at low energy before propagating them to higher-energy machines)
  - bunch-length to bucket-space matching (FCTs)
- Closed-Orbit Cycle-to-Cycle Feedback (BPMs)
  - aperture optimisation (coarse, circulating beam)
- Tune & Chromaticity Correction (BPMS, BBQ)
  - optimises space charge, ΔQ spread, dyn. aperture, beam stability
- Emittance (blow-up) Monitoring (IPMs, FCTs)

plus additional to be defined steps for high-intensity operation (e.g. optics correction, detailed collimation setup, quantative slow-extraction optimisation, ...). Presently, many of this steps are

already performed but not always systematically.
R. Steinhagen highlights that it is infeasible to achieve the target of sub-percent-level loss control using beam transformers alone as these are typically limited to accuracies in the 1 to 3% range. While small improvement may be possible, the required order of magnitude improvements are unrealistic based on long-term experience in and outside GSI.
He thus proposes to include BLMs for fast in-cycle and cycle-to-cycle loss optimisation and to cross-calibrate these to the radiation monitors that provide a slow, but absolute loss measurements. The plan is to use the BLM signals as relative indicators w.r.t. a given setup reference. R. Steinhagen showed some summary slides from S. Damjanovic illustrating that the planned SIS100 BLM system should be well sensitive enough to resolve permille transmission losses (est. minimum BLM detection threshold of about $5 \cdot 10^4$ ions/s).
R. Steinhagen provided some further examples of how the beam transformer and BLMs could be integrated and used for regular day-to-day operation (see slides for details).

## *Discussion:*

R. Bär questioned whether the readout frequency of the online dosimetry will be in the order of 10 second scale. R. Steinhagen mentioned (based on an early e-mail conversation with T. Radon) about the ongoing revision and upgrade of the present dosimetry read-out electronics and that those details need to be discussed. The temporal resolution of the radiation monitors would be too coarse in any case to allow cycle-to-cycle transmission optimisations. The main purpose of the radiation monitors is to provide an absolute calibration standard for the faster BLM-based dose measurements.

D. Ondreka and R. Steinhagen stressed that in the future the fast and DC-current transformers would need to provide the post-processed absolute particle numbers rather than beam currents only. In the future, multiple systems and users (e.g. Archiving, BTM, SBF, …) will depend on the same data, and the computation of the particle numbers (derived from the measured beam current and ion charge-state) should for consistency reasons be performed centrally rather than in the client applications. The required information could be provided by LSA or in hardware based on LOBI preference.

C. Kleffner mentioned that the particle counters used in HEST are calibrated against the primary beam intensities.

U. Weinrich asked whether the 5% loss-limit for collimators. It is presently assumed that most of these hot-spots are related to a selected number of cryo-absorbers and warm magnets. R. Steinhagen emphasised that this losses need to be kept anyway much lower than 5% based on the present radiation permit.

A. Reiter asked whether there is an ongoing R&D effort regarding distributed BLMs at CERN. R. Steinhagen affirmed this that this is primarily intended for the CLIC drive beam, tested at CTF3 and developed in partnership with ACAS at the Australian Synchrotron.

H. Weick asked whether the transformer signals and BTM thresholds could be used to also fit experimental requirements (i.e. reject too low/too high intensities being extracted to the target). R. Steinhagen confirmed that the thresholds are flexible and could also set to a tighter limits if required.

H. Weick asked whether this information is already available during the cycle in real-time. R. Bär and R. Steinhagen commented that initially the BTM will be used for monitoring purposes only before using it to suppress future beams being injected into or extracted out of the ring machine. In the future it could be also envisaged that the beam extraction is suppressed if only three out of four shots met the required intensity target. This decision should be based on pre-defined rules though.

D. Ondreka, R. Bär and R. Steinhagen highlighted that the BTM are not primarily intended to be a fast machine protection system to protect sensitive experiment equipment but rather as an optimisation tool to optimise transmission, reduce losses and thus to minimise activation of the machine. The fast protection of experimental equipment needs to specified separately. Sensitive devices – if they cannot be protected passively – will be protected through the setup-beam-flag mechanism that triggers a fast-beam-abort when the given thresholds are exceeded and the intensity ramp-up procedure. The BTM system is too slow to cover fast machine-protection scenarios.proton corresponds to an evenly distributed or localised  1 mSv/h activation of the machine ('1 W/m' criteria). R. Steinhagen explained (based on I. Strasik's HIC4FAIR presentation), that these are localised loss/activation hot-spots outside of what is intercepted by the primary and secondary collimators. It is presently assumed that most of these hot-spots are related to a selected number of cryo-absorbers and warm magnets. R. Steinhagen emphasised that this losses need to be kept anyway much lower than 5% based on the present radiation permit.

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U. Weinrich recommended that the BTM coverage should not stop at the targets. Transmission is also an important topic for secondary particle beams. Bad primary to secondary conversion rates are good indicators for tuning the machine.

U. Weinrich asked (an open) question about 'How much loss is acceptable?', 'When do you [does one] expect an answer?' and 'How many loss at which point?'. R. Steinhagen commented that while there are already hard limits derived from radiation protection regulation, that we should aim at much lower losses (ALARA principle). The main questions is how 'low' is 'reasonable' in ALARA.

U. Weinrich asked about how much activation is expected for Super-FRS at nominal intensities. H. Weick replied up to multiple Sv/h for the target. U. Weinrich commented that a per-mill of permanent losses may not be acceptable.

D. Ondreka commented that most of the losses and activation in SIS18 are known: typically in the range of a few µSv/h with a few localised hot spots in the order of a few mSv/h. For SIS100 it is expected that most of the hot-spots are at collimators, cryo-absorbers and a few warm magnets.

D. Ondreka commented that the machine aperture is at around 10 σ ( σ being the r.m.s. beam width) and that it is clear that the losses would occur at the limiting elements with 3 σ aperture. Maintenance on cryo-absorbers or extraction septum or other systematic loss positions may pose a problem. Handling is partly automated in SIS100 for baking-out.

U. Weinrich commented that for the targets the necessity for hands-on maintenance is reduced by the already designed/specified automation and remote handling. He indicated that due to the reduced level of remote handling in the synchrotrons that one may not be able to enter and simply have to wait for the radiation cool-down. U. Weinrich asked how this risk could be evaluated or handled?

R. Steinhagen (showing back-up slide 27 & 28) commented that much of machine protection is about 'risk management'. Risk – here defined as the product of consequence of an incident and its probability – needs to be counter-balanced by appropriate technical measures mitigating the risk.

U. Weinrich replied that according to Robert W. Kolb ‘planned loss is not a risk’ and these type of risk will occur with a 100% probability. Risk management is one way dealing with it but there are also other ways. D. Ondreka commented that it is not just about activation of components but rather about the probability that these fail either due to activation or their repair being impacted (blocked) by activation issues. U. Weinrich agreed that 'risk management' could be applied in this case.

R. Steinhagen highlighted that some of the risk are a continuous gradient, i.e. 'waiting for three month until a system can be repaired due to activation' would have the same impact on operation of the machine as 'three month of waiting for a spare part or repairs after a device has been damaged by the beam'. How much losses (or risk) will need to be accepted during the future FAIR operation is a top-level management decision. A more detailed machine protection discussion is planned for the next FC2WG meeting.

[A lively discussion continues….]

U. Weinrich commented that this topic is highly relevant if we talk about systematic losses in SIS100 above 1%.

D. Ondreka cautioned that the scale of many of these issues cannot be precisely predicted yet. He proposed to re-evaluate the activation issue after having operated SIS100 for a couple of weeks and to correlate the measured losses with the radiation monitors.

A. Reiter agreed that top management will decide how the facility will be operated anyhow and that one should focus on technical solutions in order to achieve a manageable risk and work out the requirements into a coherent concept. He proposed to have an off-line meeting to discuss the details.

A. Reiter commented that the HEBT may be insufficiently covered by BLMs with respect to beam transmission monitoring (only 30 BLMs). Concerning the monitoring of slow-extraction losses, he commented (agreeing with the statement made in the presentation) that the SEM monitors may probably have an accuracy of 10-15% only and that these are also affected by ageing effects that are hard to detect and quantify.

U. Weinrich supports the overall concepts and adds that this scheme should be also be flexible enough to deal with operational scenarios in the ESR and HESR storage rings (e.g. monitoring transmission before and after cooling).

D. Ondreka recommended regarding monitoring losses during slow extraction that the very sensitive cryo-comparators (mentioned by A. Reiter earlier) should ideally placed in a common transfer-line section directly after SIS100 that nearly all beams have to pass. This would help with the slow extraction machine tuning to measure how much of the stored intensity have actually been extracted. The probability that these intensities are transported through HEBT without any further high losses is considered fairly high, as the HEBT aperture is quite large, especially for the parameters of the slow extracted beam.

A. Reiter and D. Ondreka commented that it would be valuable to get direct feedback from the experiments on the actual detected particle rates. A FESA-like software  interface would be highly appreciated for integrating it into operation and the controls system.

R. Bär commented that the break-down of the overall concept into technical tasks remains open and needs to be further discussed. The rough specification made in 2012 are insufficient for this. CSCO will supervise the BTM activities but the actual implementation is part of the Slovenian in-kind (COSYLAB). The remaining details must be specified in in time before the targeted implementation in 2017. R. Bär recommends that this should start now.

***Next Steps and Actions:***

- **R. Steinhagen & R. Reimann:**
    - Collect requirements on beam transformers (agreed by/coordinated with MPLs). BI (A. Reiter) and CO should be involved in this discussions.
    - Formalise requirements and create a 'functional requirement' document and discuss again in FC2WG meeting. [N.B. document is already under preparation].
- **R. Steinhagen & F. Hagenbuck:**
    - For slow extraction: in addition to beam transformer after the SIS18/100 extraction (HEBT), a 2$^{nd}$ indicator would be needed. This indicator could be the target counter in the experiments cave → Machine-Experiment Interface

The next meeting is planned for: Wednesday 21st October 2015, 15:00-17:00 (SE 1.124c)

Reported by Ch. Hillbricht, S. Reimann, R. J. Steinhagen