FAIR Commissioning & Control Working Group

Notes from the meeting held on 17th June 2015

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

Agenda:

- SIS18 controls retrofitting & re-commissioning (*postponed*), R. Bär
- FAIR Accelerator & Beam Modes, R.J. Steinhagen

1. FAIR Accelerator & Beam Modes, R.J. Steinhagen

In his presentation (see slides), R. Steinhagen introduced and formalised the definition of '*modes'* and '*actual states'* for FAIR. The main purposes of these are

1. to communicate the intended accelerator operation to the experiments and wider FAIR community, and

2. to condition the various control sub-system responses (e.g. archiving, interlock and fast-beam-abort systems, management of critical settings, etc.)

In this context, '*modes*' are deliberate <u>user-driven</u> states (references or 'desired target') that follow and track the normal operational sequences (e.g. 'no beam' → 'pilot beam' → 'intensity ramp-up' → 'adjust' → 'stable beams for physics'), and that provide the possibility to define associated rules depending on the specific phase of operation. The mode changes will be initially tracked by operators and subsequently by semi-automated sequencer.

Some of the application using 'modes' include, for example, limiting parameter changes while the experiments are taking data (aka. 'Stable Beams' or production runs), limiting of high-intensity beam being requested or injected into a previously untested machine without having its settings being checked with low-intensity pilot beam, or to block certain operation during unsafe mode of operation (e.g. moving beam screens during production runs or while high-intensity beam is being extracted; settings changes that could impact the efficiency or safety of machine operation).

The '*actual states*' differ with respect to the '*modes*' insofar that they describe the actual <u>measured</u> state of the accelerator or beam. The 'states' perviate the accelerator and beam mode definitions, and could be equally used for ad-hoc or post condition of the control system (e.g. beam-based interlocks). Some of the actual states that are proposed and that shall be integrated and transmitted alongside with the modes are the Beam-Presence-Flag (BPF), the Setup-Beam-Flag (SBF), and the Injection- and Extraction-Permit that are defined in more detail below. While the transmission of the modes is not time-critical, there are certain real-time requirements on the transmission of BPF, SBF and Injection/Extraction Permit since they are foreseen to be used also by the interlock and machine protection system.

R. Steinhagen stresses that the definition of 'modes' should not be mixed with 'actual states' to prevent circular dependencies, priority or causality inversions. For example: while the 'No Beam' mode declares the intend (as an agreement) that there will be no beam in the machine, only the 'Beam Presence Flag' measures the actual state whether there is (or was) beam in the machine. An consequence and trivial example rule using this definition would be to issue an interlock if the if the 'BPF=true' while the beam mode 'No Beam' is set.

Based on earlier discussions with CO and OP, R. Steinhagen proposed two groups of modes:

- *'Accelerator (or Machine) Modes'*, that cover rule sets and operational sequence outside of beam operation and that are defined per accelerator or transfer-line segment,

- '*Beam Modes*', that cover rule sets during beam operation and that are defined per accelerator or transfer-line segment <u>and</u> Beam-Production-Chain (BPC).

Accelerator Modes:

The modes to be used as 'Accelerator Modes' follow the existing annual life-cycle of the accelerator facility and are formalised as:

A.1)   SHUT-DOWN: used when the machine is in a mode of long-term maintenance or repairs, and could imply (as an example rule) the possibility of open or controlled access, and the machine being not powered. Further discussions are needed whether this mode needs to distinguish a 'warm' and 'cold' shut-down (e.g. SIS100 being kept at 4 K).

A.2)   COOLDOWN: required in particular for SIS100 and Super-FRS during the period when the machines are being cooled down from ambient temperature by the cryo-system (lasting typ. 2-3 weeks), and could, for example, imply limited or no access (if safety necessitates it).

A.3)   BAKE-OUT (SIS18, HEBT, ...): which is similar mode to 'COOLDOWN' for the other normal conducting accelerators and transfer-lines but covering the vacuum bake-out period (also about 2 weeks).

A.4)   WARM-UP (SIS100, SFRS)

A.5)   RECOVERY (SIS100, SFRS): used after, for example, a major quench or partial vacuum loss outside of normal beam operation and lasting typically few hours to days. This mode would include pre-cycling of magnets to stabilise their hysteresis and revalidation of the proper function of power converter, quench protection systems, etc.

A.6)   MACHINE-CHECKOUT: which covers operational tests and dry-runs without beam in view of beam operation (e.g. power converter calibration, magnet patrol, etc.). This mode is typically used only once per year, only after a long shut-down, and typically a few weeks before regular re-commissioning and operation with beam starts. This would also mark the end of regular shut-down operation and start of operation with beam.

A.7)   MACHINE-TEST: which a priori is similar but for accounting purposes distinguished from MACHINE-CHECKOUT. The mode is intended to be used to cover similar activities but during beam operation. The expectation is that the machine is closed and all system in a ready-for-beam state to permit short-lasting dry-runs to test new control schemes, new front-ends, RF conditioning, tests that can be done without beam (e.g. when ion sources are being exchanged or the linac is unavailable) and for OP training purposes. This mode is needed from an operational point of view but is used if the time allocated should neither be accounted as 'Physics' nor 'Machine-Development' during the annual statistics.

A.8)   ACCESS: intended to be used whenever a controlled machine access is given during beam operation for specific interventions (repair, change of experimental setup). The main purpose of this mode is to keep track of beam (un-)availability during beam operation (annual accounting) and to stop the concerned part of the machine in a controlled way (ie. controlled soft-powering-down of magnets, rather than using interlocks that abruptly stop the power supplies and leave them in a fault state after an access).

The next set of accelerator modes describe normal beam operation but are proposed to be further divided to distinguish between the main aim or user of accelerator operation and to provide a more fine-grained accounting of beam times spend for

A.9)   BEAM-SETUP, MACHINE SETUP or COMMISSIONING (final mode name tbd.): used during the initial and subsequent re-commissioning after long shut-down and could include OP training with beam.

A.10)   PHYSICS: e.g. when the primary intended purpose of the machine is to deliver beam for atomic, anti-matter, nuclear and bio-medical applications. Decisions that would affect the beam availability (e.g. inserting of screens for parallel users) would be driven by the primary experiments with this mode.

A.11)   MACHINE DEVELOPMENT: e.g. when the primary intended purpose of the machine is to perform beam physics or accelerator physics studies. During this mode the prerogative of, for example, inserting screens into transfer-lines would be at the discretion of the accelerator physics groups.

R. Steinhagen stresses that (besides formalising their names) these mode definitions 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.
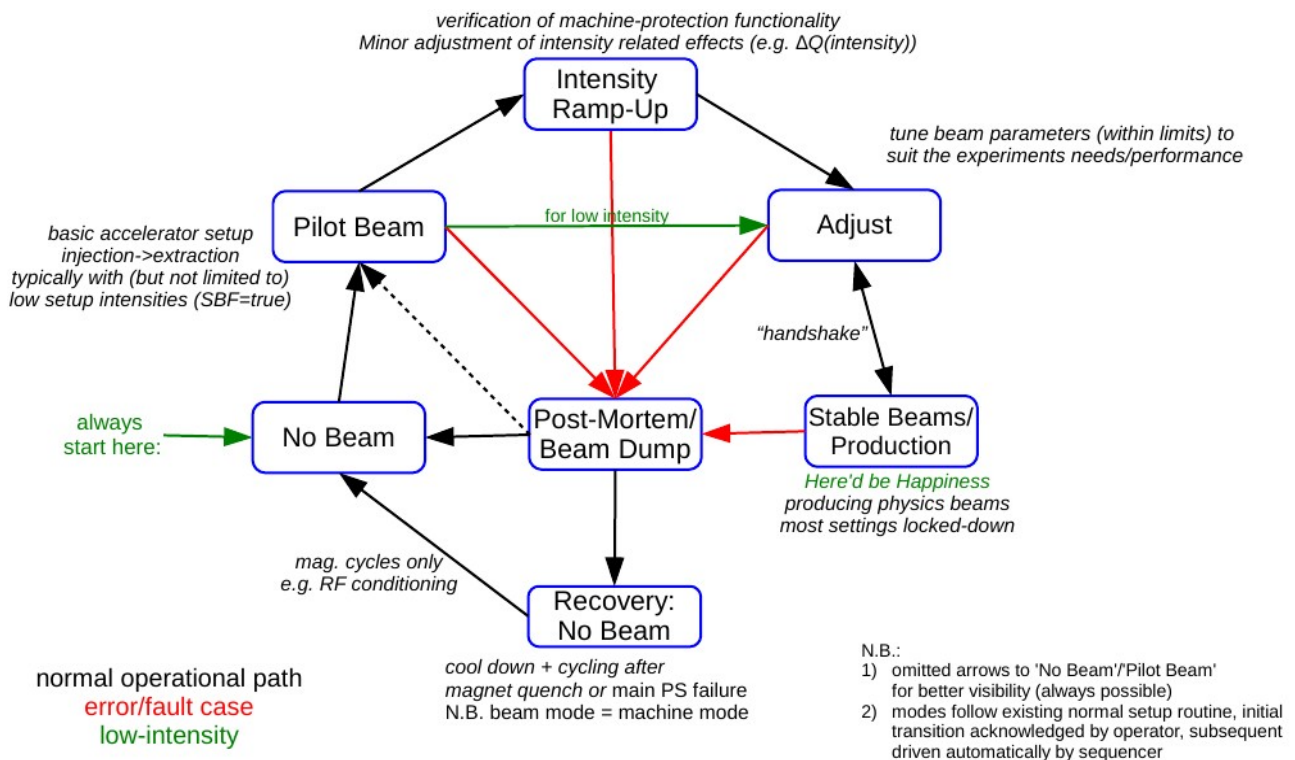
Beam Modes:

The 'Beam Modes' follow the life-cycle (e.g. 'no beam' → 'pilot beam' → 'intensity ramp-up' → 'adjust' → 'stable beams for physics') of the so called '*Beam-Production-Chain*' (BPC). The BPC is an organisational control system structure to manage parallel operation and beam transfer through the FAIR accelerator facility. It describes a 'beam' through the facility including the sequence and

parameters of beam lines and accelerators, starting from the ion-source up to an experimental cave (e.g. APPA, CBM, Super-FRS, ...).

The BPC structure includes the definition of target beam parameters (set values) like, for example, isotope type, energy per nucleon, charge per nucleon, peak intensity, etc. Several BPC are grouped to a pre-defined '*Beam Pattern*' that is typically executed periodically. While being pre-defined, these patterns can, however, be changed within minutes.

The '*Beam Modes*' are specific for a given BPC but also transfer-line segment (or group of the latter). This implies that e.g. different accelerator can have different beam modes (e.g. the beam mode for the BPC delivering beam to CBM being 'Pilot Beam' in SIS18 and 'No Beam' in SIS100). The proposed state diagram is illustrated in the following figure:

The first beam modes follow the natural sequence of how new beams are typically being set-up in an accelerator. In that respect (similar to the Accelerator Modes) these are not new but formalise the existing operation concept, integrate and would make the control system aware of them:

B.1) NO BEAM: used by the control system to suppress by design beam requests or injections into a given ring or transfer-line.

B.2) PILOT BEAM: used while establishing the main machine functions and parameters such as injection steering, RF capture, ramp, orbit, tune and chromaticity, simple optics checks, proper slow or fast extraction. This mode implies that these operations are done typically with low setup-beam intensities, and that optics parameters can be changed without limits on their value or range.

B.3) INTENSITY RAMP-UP: used while ramping up beam intensities and after the basic accelerator functions have been established. This mode is used to performe minor adjustments related to increasing the beam intensities and to validate related machine

protection functionalities. It would be also linked to more strict limits on optics and parameter changes. This mode is necessary for a safe and reliable operation with high-intensities but could be skipped if operation with low beam intensities is targetd.

B.4)   ADJUST: while the main focus of the 'Pilot Beam' and 'Intensity Ramp-up' mode focus on the beam setup from an accelerator point of view, this mode focuses and is used to perform minor parameter changes or re-tuning in view of achieving the physics experiment's parameters.

B.5)   STABLE BEAMS: used to indicate that the main intend is to deliver stable beam to the given experiment. Very limited machine tuning and (if at all) parameter changes would be allowed during this mode in order to avoid transients or spikes that would hamper the experiment's data taking. Leaving this mode may require a hand-shake or release by the experiments to provide them the possibility to return their detectors into a safe state.

B.6)   POST-MORTEM or BEAM-DUMP: used in response to a quench, machine-protection action, partial vacuum loss (e.g. dynamic vacuum loss) or another major beam loss that needs to be analysed before normal beam operation can be continued.

B.7)   RECOVERY: used to indicate the time period required for recovering from a severe post-mortem (e.g. quench of a single or string of magnets) and covers the period to validate powering, cycling of the magnets, and other essential systems.

R. Steinhagen mentioned that additional modes such as 'INJECTION','ACCUMULATION', 'RAMP' and 'FLAT-TOP' may be considered in particular for slow-cycling storage rings (ie. ESR and HESR). Their necessity needs to be clarified.

Actual States:

Among the many possible actual states, R. Steinhagen highlights the *'Beam-Presence-Flag' (BPF)*, 'Setup-Beam-Flag' (SBF), and Injection- or Extraction-Permit:

The *'Beam-Presence-Flag'* shall indicate that a given BPC and associated settings have been validated and are compatible with pilot- or physics-beam. The main purpose of this flag is to prevent high-intensity injections into an 'empty' machine with new untested magnetic settings or modified machine conditions that might be potentially incompatible with machine-protection or activation minimisation of the machine. The flag would need to be defined per accelerator or transfer-line segment (where necessary). The flag is being set whenever the basic accelerator function has been confirmed with beam (e.g. acceptable performance of: injection, RF capture, acceleration/ramp, transmission, orbit, Q/Q', loss patterns, ...). The initial checks and references would be taken by an operator or experienced machine expert. Subsequent cycles would be re-validated and checked against these references. The BPF would expire if untested for a prolonged period or if settings have substantially changed, and could force, for example, re-checking the cycle settings with pilot beam before continuing with high-intensity beams.

The *'Setup-Beam-Flag[1]'* shall indicate beams (with typically low-intensities) used specifically for the initial setup of the BPC. The definition derives from the experience and existing usage at LHC: too strict interlocks and rules that are required to ensure a safe and reliable high-intensity operation may at the same unnecessarily impact machine availability during beam setup with low-intensities. The SBF facilitates the flexibility of masking some of these interlocks during low-intensity operation, while ensuring that these interlocks are taken automatically into account when operating with unsafe high-intensity beam. The flag would need to be derived automatically from the beam current transformer (simple threshold). Most of the SBF-maskable interlock candidates are related to more complex or beam-instrumentation-derived interlocks such as beam transmission, beam loss monitoring, beam screens and multi-wire grids.

Some use-case and proposed rule examples to illustrate the SBF: a) While 20% beam transmissions may be temporarily acceptable during setup or low-intensity operation (ie. transmission interlock being masked), the associated interlock should not be kept permanently disabled or forgotten once moving to high-intensity operation. b) In order to self-protect sensitive beam screens, wire-grids and other similar devices, these devices would by-default create an extraction (or injection) interlock (↔ fail-safe logic) whenever they are inserted into the beam line or ring. However, these interlock could be masked if the 'SBF==true' and possible other additional beam mode requirements are fulfilled (e.g. not in 'STABLE BEAMS' or 'INTENSITY RAMP-UP', etc.).

Discussion:

S. Pietri and M. Steck asked whether the 'modes' would be used to regulate access to the experiments or ensure its safety? R. Bär reassures that the 'mode' definition does not replace the existing personnel safety system or organisational structures. The definition is complementary and allows the definition of additional rules (e.g. safe slow power-down of main supplies). R. Steinhagen added that this would be also used for accounting purposes (availability analysis) to keep track of the amount of time spend for, for example, accesses, adjust, etc.

M. Steck pointed out that there are loops in the diagram for the beam mode state-machine. R. Steinhagen confirmed and explained that this is intrinsic to the beam setup being typically an iterative process. Sometimes it is necessary to step back to safer beams and to re-do some of the earlier setup and optimisations before continuing operation with high(er) beam intensities.

S. Pietri and D. Ondreka noted that some of the proposed accounting is presently treated differently and differs for some experiments, for example, the period covering 'ADJUST' (German: *"Nach-Regeln/Tunen"*) is presently not allocated to the experimental users but considered as part of the machine setup. R. Steinhagen emphasised that the initial definition should be considered similar to 'hooks' which can be used to attach given rules. A the present stage the focus should be on the definition and agreement on a limited but sufficient number of modes. The details of the individual specific rules or how these modes accounted within the annual beam availability

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1 SBF has been originally coined as 'safe beam flag', but subsequently replaced by the notion of 'setup' as some of the setup operations that require the SBF need to be done with unsafe beam intensities, also because since there is no unconditional 'safe intensity' for some very sensitive devices (e.g. SIS100 e.-s. septa, Si-tracker), and to stick to a common terminology already established by other facilities (CERN).

analysis need to be addressed at a later stage. R. Bär and D. Ondreka agreed that we should focus on a set of modes for all machines first and to discuss the transitions between them later. They emphasised, that the 'mode' functionality must become part of the control system even if there are no rules defined and independent on the number of modes.

A. Reiter stressed that the rules and procedures related to the 'ADJUST' and 'INTENSITY-RAMP-UP' modes should be defined in close cooperation with and feedback from experiments. R. Bär and R. Steinhagen affirmed that this necessary and already the case (e.g. regarding Super-FRS).

J. Stadlmann asked whether additional such as 'PILOT & DUMP' and 'INTENSITY RAMP-UP & DUMP' should be defined as well to permit setup without sending (potentially unstable) beam to the experiments. D. Ondreka commented that this would be more a machine protection issue and not handled by the modes. The extraction inhibit would be more useful for this application. R. Steinhagen explained that in addition that this case could be covered with the ring, for example, being in 'PILOT' and the subsequent extraction beam-line in 'NO-BEAM' which would (/should) suppress the extraction. D. Ondreka commented that this would presently not be as easy since the dump is a different particle destination.

A. Reiter asked whether a dedicated mode would be needed that allows a (partial) hand-over of the machine control to the experiments. R. Steinhagen replied that this could be covered by the 'ADJUST' mode.

D. Ondreka emphasised that the definition of an 'UNSTABLE-BEAM' mode is rather a state. R. Steinhagen agreed. This mode has been introduced based on previous experience and similar definition for the LHC experiments but will be dropped for FAIR. [N.B. also already removed from the state diagram]

M. Steck indicated that the definition of 'beam quality' is missing. R. Steinhagen confirmed that this type of feedback from experiments is important but should be treated as an 'actual state'.

D. Ondreka mentioned that the experiments would need the possibility to inhibit the next beam extraction. R. Bär explained that this would be covered by machine-protection (e.g. fast-abort-system).

D. Ondreka mentioned that rather than forcing the 'Setup-Beam-Flag' to 'true' for testing purposes, that the flag should be kept as simple and robust as possible, and that there should be another general flag that forces the required test condition in the front-ends.

R. Bär asked whether different SBF thresholds are needed for different beams or beam instrumentation devices. A. Reiter proposed that the lowest reasonable threshold could be taken.

J. Stadlmann asked – followed by a longer discussion – whether the SBF thresholds could be adjusted dynamically, for example, depending on the specific device that has been moved into the beam-line. R. Bär replied that this could be done but that this would be also much harder to implement in a safe and reliable way.

S. Pietri asked how this 'mode' concept would fit the Super-FRS concept and requirements. R. Bär

proposed to reiterate off-line on this and to re-discuss the concept and Super-FRS use-case in detail.

R. Bär asked for a general brief feedback concerning the concept: M. Stock felt that it was a bit confusing at first. R. Bär highlighted that the concept is already being practised during day-to-day operation but now being formalised, rephrased and proposed to be made available also for the control system. S. Reimann confirmed that the proposed scheme would work as it is already being used by OP. J. Stadlmann reckoned that this would work and that it would simplify the presently manual tracking of modes. C. Kleffner asked whether machine protection and personnel safety system would be separate from this. R. Bär affirmed this. R. Steinhagen stressed that this would be the first step towards an automated and formalised agreement of the accelerator operation sequence. F. Hagenbuck commented that the proposed modes and their usage look structured. S. Pietri agreed that the proposed scheme would fit also Super-FRS requirements and that the details need to be further discussed.

R. Steinhagen urged the participants to verify and reflect on the presented mode concept and to forward him any further questions or comments. He will organise a dedicated follow-up meeting to finalise the modes (target: Q3-2015)

**Next Steps and Actions*:*

- **M. Steck (ESR) & D. Prasuhn HESR**: need to verify whether the proposed mode structure would fit ESR and HESR requirements, or whether the additional tentatively proposed modes 'INJECTION', 'ACCUMULATION', 'RAMP' and 'FLAT-TOP' are needed as well.
- **FC^{2}WG-all:** will provide input and further requirements, if necessary.
- **R. Steinhagen** will collect further requirements, prepares a follow-up meeting, finalise and circulate the 'accelerator and beam mode' specification. Target: end Q3-2015

The next meeting is planned for: Wednesday 1st July 2015, 15:00-17:00 (SE 1.124c)

Reported by J. Fitzek, R. J. Steinhagen