FAIR Requirements for Tune Determination

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Demands for the new FAIR facility

FAIR (Facility for Antiproton and Ion Research) will be a very versatile proton and ion accelerator facility. High current proton beams will be accelerated by a new LINAC, composed of CH-structures, injected to the existing SIS18 heavy ion synchrotron used as a booster with a maximum rigidity of 18 Tm and then further accelerated to 29 GeV in the new SIS100 synchrotron having 100 Tm maximum rigidity. The protons will be used for antiproton production. For the ion operation, the existing UNILAC, after some up-grade, will serve as the injector for very high currents of all ion species. The existing SIS18 will serve as a booster. The new SIS100 will accelerate the ions to an sufficient energy for an effective production of radioactive ion beams (RIB) within an in-flight production target and a complex separation spectrometer, the super-conducting fragment separator S-FRS. The RIBs as well as stable ions will be injected in several storage rings for cooling purposes and various experiments. The main advantage of the new facility is the possibility to increase the amount of primary heavy ions by about a factor of 100 with SIS100 (depending on the ion species) as well as an improved transmission of the RIBs up to a factor of 100 by the new S-FRS. Versatile investigations of the RIB species in the storages rings are foreseen, which requires a fast de-bunching scheme and complex stochastic and electron cooling procedures. Deceleration of the RIBs and antiprotons down to 4 MeV/u is an integral part of the foreseen operation at FAIR. The main challenges for the high current operation in SIS100 are described below. More details and meaningful plots are presented in the corresponding talk.

Challenges for high current operation of SIS100

For the RIB production the SIS100 operation scenario is based on storage and acceleration of low charge state ions to prevent for particles losses at several stripper sections prior to SIS18 and between SIS18 and SIS100. For the design ion U^{28+} the injection energy is only 200 MeV/u (as given by the 18 Tm max. rigidity of SIS18). Four batches with two bunches each will build up a complete SIS100 filling. For these parameters several topics are important to estimate the requirements for the closed orbit and tune stabilization of beams for the SIS100 high current ion acceleration:

- **Large tune spread**: Due to the low charge states for the RIB production, the injection energy is only 200 MeV/u in case of U^{28+}. For the design current of 5·10^{10} ions per bunch, this leads to a large incoherent tune spread of ΔQ=0.3. As given by the maximal ramp rate of the proceeding SIS18, the storage time of the first batch is about 1 s and the beam has to be stabilized during this relatively long duration.

- **Low dynamic aperture**: Super-conducting magnets will be used for the dipoles and quadrupoles at SIS100. These super-ferric magnets are ramped within 300 ms; this fast ramping is required to achieve a large amount of average ion rate delivery to the production target. For the properties of the precursor magnet type constructed at JINR at Dubna and used at Nucletron, the dynamic aperture is calculated with the code MICROMAP. At injection energy, the dynamic aperture is only about 3·σ, with σ being the standard deviation of the beam size. Taking a realistic space charge tune spread into account as given for the 5·10^{10} U^{28+}, the dynamic aperture shrinks well below 3·σ and the rate of beam loss has to be taking into account in an accurate manner. During the maximum storage for the first batch of about 1 s, the beam has to be stabilized to minimize this beam loss. This concerns the closed orbit as well as the tune to prevent resonance cursing for the beam with large space charge tune spread. Due to the large tune spread an accuracy of about Q=0.01 seems to be sufficient for these parameters.

- **Beam loss by electron stripping**: For the low charge state ions, e.g. the design case of U^{28+} electron stripping becomes the dominate beam loss process and special catchers for the dump of the charge changing ions (U^{29+} in the design case) are foreseen in the SIS100. With them a significant increase of the vacuum pressure due to beam induced desorption from the pipe walls should be avoided. Due to the large energy loss at the wall surface by slow heavy ions, this
desorption is the dominant process for a dynamic vacuum pressure increase: The desorbed molecules can then trigger an avalanche effect due to an increase electron stripping rate leading to a vacuum induced instability. But also a significant beam loss due to the crossing of the dynamic aperture leads can lead to this avalanche behavior, even though the loss might better be distributed along the synchrotron circumference. In connection with the low dynamic aperture, beam stabilization is required.

- **Fast acceleration:** At SIS100 a ramp rate of 3 T/s is foreseen, which is relatively fast for super-ferric magnets, resulting in a total ramping time of about 0.5 s. During this time, the closed orbit and the tune has to be stabilized by a fast feedback with an anticipated reaction time of 10 ms only. This fast reaction time is difficult to realize, even though 10 ms correspond to about 1000 turns in the 1100 m long SIS100, a turn-number where also the reaction at LHC is foreseen. Presently, the dynamic effects of the magnets during ramping and the resulting variation for closed orbit and tune is not sufficient well investigated to give a specification of the required beam stabilization accuracy.

- **Bunch gymnastics:** For the transfer from SIS100 to the storage rings, bunch rotation is required, in particular for RIB production to minimize the longitudinal emittance enlargement at the target. Prior to the bunch compression, a controlled de-bunching to one barrier bucket within about 100 ms is foreseen. The diagnostics have to able to cope with the different bandwidth and time requirements during this manipulation.

**Challenges for operation of the storage rings**

The storage rings will mostly be operated with a low number of RIBs or antiprotons. Therefore, the beam diagnostics is designed to provide the lowest possible detection threshold. Cooling methods are applied, but stochastic cooling works most efficient, if a close orbit feedback counteracts the coherent beam deviation from the ideal orbit. For acceleration a feedback should prevent for beam losses. More challenging is the deceleration of the RIBs and antiprotons foreseen in RESR and NESR with a ramp rate of 1 T/s using normal conducting magnets. Due to the emittance enlargement, which can only be partly counteracted by electron cooling due to the relatively long time constant of the RIB case, a feedback is required with a reaction time of about 10 ms, i.e. comparable parameters as for the SIS100 case. The use of normal conducting magnets might relax the demands on the feedback.

**Peculiarities and requirements for tune measurements and feedback at FAIR**

Non-relativistic beam are stored prior to the acceleration within the super-ferric SIS100. For the BPM system, the change of the revolution time from 9.1 μs to 4.5 μs for the design case of U^{28+} ions is demanding for the technical realization. Moreover, the long barrier bucket and the short bunch after rotation calls for a large bandwidth of the BPM analogue electronics. The tune measurement and feedback system have to be capable for these varying bunch-length, repetition rate and amplitude. Presently, a possible solution is under first investigation using a direct digitalization of the BPM signals with 125 MSa/s ADC and dedicated digital signal processing, as described by U. Rauch within this session. During the ≈0.5 s long acceleration at SIS100 a possible tune measurement and feedback system should work with a reaction time of ≈10 ms or about 1000 turns, which is quite fast compared to existing systems. Moreover, only a very weak excitation will be allowed due to the small dynamic aperture leading to a challenging technical realization. The tune spread for SIS100 design case U^{28+} is estimated to be ΔQ=0.3 at injection. Most existing tune measurement systems are not designed for such a large value and it is not clear, whether demanding problems occur for these parameters. For the storage rings, the large dynamic range in terms of amplitude and frequency variation seems to be the most demanding task as the feedback system will mainly be used during acceleration or deceleration of low amount of RIBs or antiprotons.

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