Behavior of the planned RF feedback loops under beam loading during a reference SIS100 cycle*

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It is well known that beamloading effects in accelerating cavities can have a serious impact on the beam quality. In order to prevent emittance growth and to keep beam loss low during acceleration, detailed simulations are necessary to evaluate the effects on the cavity and its low level RF feedback systems. This situation is aggravated by the fact that in a SIS100 scenario two out of ten buckets have to stay empty. Up to now the closed loop performance of the overall cavity system is still an open topic. Therefore a detailed study has been started.

Planned architecture and requirements

For most operating conditions ferrite-cavities can be well modeled as parallel, time variant RLC-circuits [1]. In order to analyze the influence of beamloading and empty buckets a simulation model has been set up consisting of the cavity itself, its attached control loops and a macro-particle nonlinear tracking simulation. The LLRF systems consist of the amplitude control loop, the resonance frequency control and the cavity synchronization. The amplitude control loop is planned as a linear PI controller in order to achieve stationary accuracy. The resonance frequency controller is as well a PI element and possesses additionally a feed-forward path which maps the desired resonance frequency to the desired bias current. Finally the cavity synchronization is a P-type controller with inherent integral type behavior.

It can be shown that all three control loops are influenced by beam loading. As a phase accuracy of better than $\pm 3^\circ$ and an amplitude accuracy of $\pm 6\%$ are intended to guarantee a satisfactory beam quality [2], beam loading effects must not be neglected. Especially the induced parasitic frequencies due to empty buckets are an open topic up to now and the planned control architecture has to be validated with respect to this issue.

Simulation of the RIB $^{238}U^{28+}$ 2.7GeV cycle

Nonlinear tracking simulations of the full acceleration cycle were performed for 5×10^{11} $^{238}U^{28+}$ ions with an injection energy of 1.976×10^8eV/u and an extraction energy of 2.7×10^9eV/u according to the official SIS100 cycle document [3]. The maximum synchronous phase during the cycle is 59.28° with a maximum gap voltage of 372.53kV. The bunches are injected in groups of two, letting the last two buckets of in total ten empty. The shape of two bunches during acceleration, near flat top, is shown in Fig.1, where the peak beam current reaches about 6 A . The emittance growth depends on the bunch position. While the first bunch growth by 2.1% the sixth bunch shows an emittance growth of 8.4%. Particle losses are hardly noticeable and will be dominated by other effects. The objective of the simulation is to serve as a proof of principle for the closed-loop control systems planned for SIS100. There is still the possibility to improve the beam quality, for example by temporarily de-activating individual cavities.

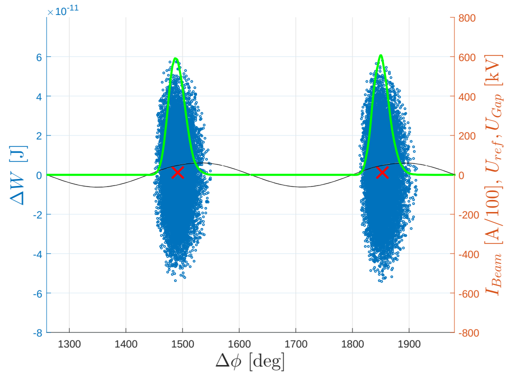

Figure 1: Two filled buckets during acceleration: particles (blue), beam current (green), gap voltage (black) and center of gravity (red)

Outlook

The results obtained in the detailed simulation study described in this contribution show that the planned low level RF control loops are able to deal with beam loading effects during the extremal RIB $^{238}U^{28+}$ cycle and maintain the RF accelerating voltage at the desired set point. Current work focuses on the influence of beam loading on the LLRF systems during a bunch-to-bucket-transfer from SIS18 to SIS100 and the arising transient effects. In future the influence of dipole beam oscillations on the stability and performance of the controlled cavity dynamics is going to be analyzed.

References

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