Design and tuning of digital filters for RF feedback loops in heavy-ion synchrotrons*

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Damping of longitudinal coherent bunched-beam oscillations are needed in SIS18 and SIS100 to stabilize the beam, prevent emittance growth and keep beam loss low during acceleration. In last year's work several approaches of digital filters for beam-phase control have been examined. An FIR (finite impulse response) filter with 3 taps, cf. [1], has been successfully used at GSI in several machine experiments for a beam- phase control system and a longitudinal feedback system. In principle, much more taps can be used, but it is still an open topic, whether more complex filters will lead to better results. Therefore, a detailed control-theoretic study has been started and the progress is reported in the following.

Requirements and filter properties

A numerical differentiator approach based on a least squares algorithm [2] has been chosen as an alternative to the established 3-tap filter. Both filters make use of the inner product between two vectors in an FIR filter design. The non-zero coefficients of the 3-tap filter, together with a certain amount of zero taps, form a bias-free bandpass filter. The length of the derivative-estimator filter has to be adapted during the acceleration ramp. Currently, it is assumed that the optimal length depends on the incoherent linear synchrotron frequency, but alternatives will be studied in detail.

The future hardware platform for the filter implementation will allow filters with up to 64 non-zero taps. A filter bank will be used to select different filters based on available parameters such as the synchrotron frequency. Alternatively, a continuous tuning of the coefficients will be possible [3].

Simulation and outlook

Nonlinear tracking simulations were performed for Ar 18+ as ion species at an energy of 11.4 MeV/u for a stationary operation with a linear synchrotron frequency of 740 Hz.

In this case the derivative-estimator has a length of L = 52 non-zero taps without additional zero-taps and is tuned to a high damping rate.

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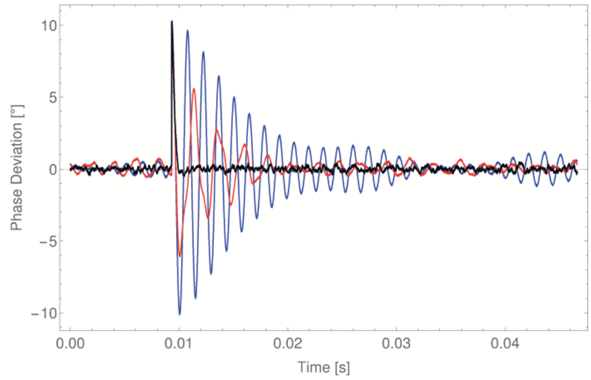

Figure 1: Beam-phase with respect to uncorrected Group-DDS: Open-loop (blue), controller with derivative-estimator (black), controller with 3-tap filter (red), with a 10° distortion at 0.01s

A typical simulation result is shown in Fig.1. A disturbance of 10° on the beam phase is applied at 0.01s to intentionally excite a feedback reaction. The results indicate that the 3-tap- filter has smaller emittance growth, whereas the derivative-estimator damps the oscillation much faster. The emittance growth using the 3-tap filter is over 3 times smaller compared to using the derivative-estimator filter, although the beam-phase is stabilized much faster by the derivative estimator.

Currently under investigation is the influence of the filter length and gain on emittance growth for the derivative estimator, as well as tuning rules for the acceleration process, with respect to ion species, bunch lengths, etc.

In future both controller designs will be studied on slow and fast acceleration ramps, as they occur in the FAIR project. Another important subject to be studied is the influence of the cavity dynamics on the stability and efficiency.

References

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