Analysis of a Digital Beam Phase Control System

B. Zipfel, K. Fricke-Neuderth, H. Klingbeil*, M. Kumm*, P. Moritz*,
University of Applied Sciences - Fulda, Marquardstraße 35, D-36039 Fulda
**GSI, Gesellschaft für Schwerionenforschung, Planckstraße 1, D-64291 Darmstadt*

FH-Fulda FAIR

Abstract

At GSI a closed loop beam phase control is planned, which will be used to damp coherent dipole oscillations of particle bunches in the SIS12/18. The system is based on a DSP System for high-precision phase and amplitude detection [1], which has been developed at GSI based on commercial DSP, ADC and DAC modules and is also applied for cavity synchronisation.
Taking into account limited computing power and given signal processing delays, as well as noise on analogue cables, the loop stability limit is determined by simulation. Influence on beam loss and longitudinal phase space plots can be analysed. In future the beam phase control will reduce emittance blow up during acceleration in SIS12/18.

Simulating Control Parameters

Based on the phase detector and the cavity synchronisation system used in the SIS18 [2], simulations of the closed loop control over the whole accelerating cycle were done. The technical parameters can be varied by observing the effect on the longitudinal phase space of the particle bunch.

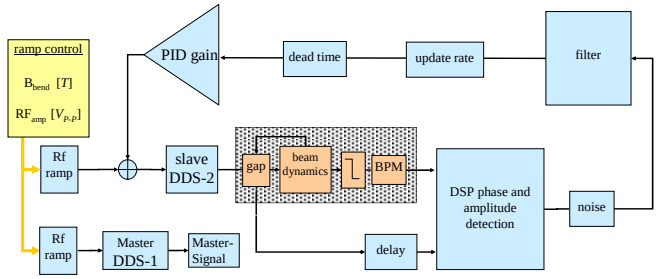


Fig. 1: Control Loop Diagram of Simulation

By loading different accelerating timing schemes of typical operating modes (virtual accelerators), stable operation can be proven. For given system constants, like delays, 'update rate' and 'dead time' of the control loop, adequate parameters for feed back gain can be tested. The behavior of the control loop receiving a noisy phase detection signal for input can be studied.

DSP Phase Detection

The simulated method of phase detection, it can be selected from three in principle different possibilities, with in general different results shown in the following figure.

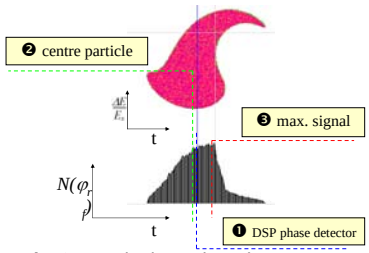


Fig. 2: Bunch phase detection

Method ❶ uses an algorithm to identify the bunch phase quite similar to that of the DSP phase detection unit [1]. For this the bunch phase is calculated from the phasor of the fundamental wave f_0 of the BPM signal. (Simulation solves the Fourier integral for the fundamental – DSP does a I-Q demodulation after band pass of the fundamental). The method ❷ uses the particle at the centre of bunch at start to define the bunch phase (only for testing purposes). And method ❸ sets the time of maximum signal of the bunch for its phase.

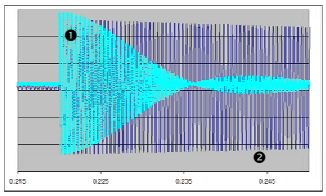


Fig. 3: Differences in bunch phase detection using method ❶ or ❷

Outlook

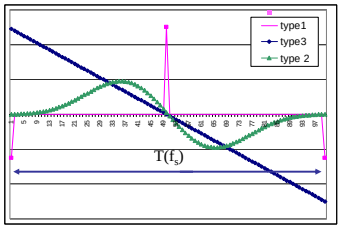
Future simulations should enable investigation of stability limits including additional effects:

- Longitudinal Multi-Bunch oscillation
- Longitudinal Quadrupol and higher order single mode oscillation
- Multi harmonic acceleration
- Beam Loading and Space charge

Filter Selection

A special digital filter with variable pass band is used to convert the beam phase signal to an adequate correction signal for the accelerating RF-voltage. In order to get a proper correction signal the digital filter eliminates noise, but it amplifies phase oscillation signals in the matched bandwidth of the synchrotron frequency of the individual accelerated particles. The filter is not DC coupled to allow changes of the synchronous phase without fixing it to a predefined value. Anyhow the implementation of this digital filter seems to be straightforward and the realisation does not require excessive computational power.

Fig. 4: Different filter coefficients can be loaded for simulation. The appropriate filter delay, respectively its number of filter coefficients, varies proportional with the synchrotron period. The calculated synchrotron frequency can be provided by the central control system. Filter type 1 gives good results compared to a simple implementation.



First Results

Simulations show good results when using a filter with variable delay for damping dipole oscillation over the whole frequency range (500- 5000Hz). Especially during RF capture, dipole oscillation will not be damped if the pass band of the filter is not well matched to the dipole oscillation frequency.

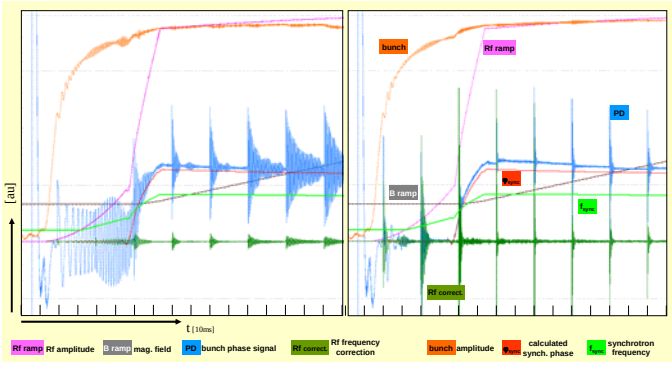


Fig. 5: Damping the dipole oscillation of a bunch with a constant filter delay (left) and with a variable pass band (right). Every 20 ms the bunch phase is displaced by an offset of 15°.

Beam Quality Analysis

During simulation, emittance of bunch can be calculated. The spectral analyses of the longitudinal bunch signal provides information for feedback amplifier systems for example. Distortion of gap signal can be visualised.

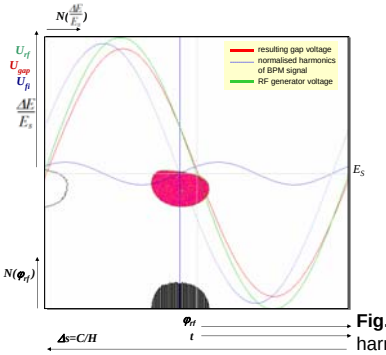


Fig. 6: Bunch emittance, profile and harmonics of expected BPM signal.

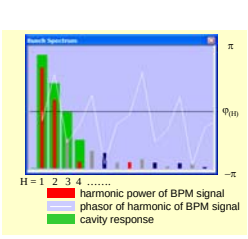


Fig. 7: BPM signal with cavity response is used to identify

References

[1] H. Klingbeil: A Fast DSP-Based Phase-Detector for Closed-Loop RF Control in Synchrotrons, IEEE Trans. Inst. Meas., Vol. 54, No. 3, June 2005, p.1209-1213.
[2] H. Klingbeil: A Cavity Synchronization System For Heavy Ion Synchrotrons Based on DSP, DDS and FPGA Technology,
Poster presented at this workshop

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