THE DAMPING OF LONGITUDINAL QUADRUPOLE OSCILLATIONS AT GSI*

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Abstract

SIS100 is a synchrotron that will be built as a part of the new accelerator centre called Facility for Antiproton and Ion Research (FAIR) at GSI [2]. It is planned to accelerate high intensity ion beams, making it necessary to damp coherent longitudinal coupled and uncoupled bunch oscillations [9, 10]. Therefore, an RF control system was designed giving the possibility to damp such oscillations. Its processing part is based on a digital signal processor (DSP) whose advantage is its adaptability to different problems by software changes. With this system measured phase and amplitude oscillations of bunched ion beams are processed. Experiments have been set up at the existing synchrotron SIS12/18 at GSI concentrating on the damping of longitudinal coupled bunch quadrupole oscillations of the lowest order. Based on these experiments one can estimate up to which growth rate a damping in the synchrotron SIS100 will be possible. The configuration of the electronic system will be described and results of the measurements using the electronic feedback damping system will be reported.

DSP BASED PROCESSING SYSTEM

During the machine experiments at SIS12/18 at GSI a DSP based processing system has been used. The principle of the phase oscillation and amplitude oscillation detection and damping with this system is shown in Fig. 1 and can be described as follows [6, 8].

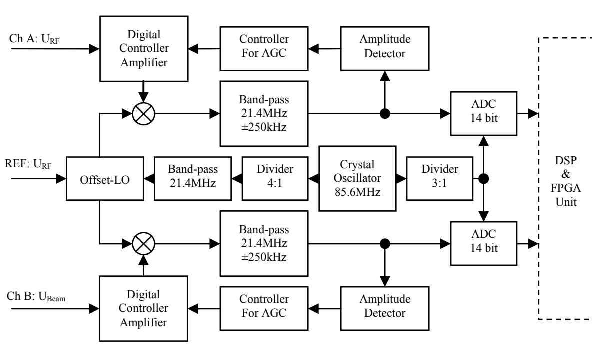

Figure 1: Hardware architecture of the analogue signal processing.

Analogue pre-processing part

For the phase and amplitude measurement the analogue pre-processing part converts the gap signal and the beam signal to a fixed intermediate frequency (IF). For this purpose the radio frequency (RF) signal which is also used to feed the main accelerating cavity is routed to a local oscillator (LO). The other input of the offset LO is fed by a frequency generator which generates the IF. The output signal is used for both channels of the phase detector where it is mixed with the RF signal of interest. To measure the amplitude only the beam signal channel is relevant.

The desired IF range of both channels is selected by a band-pass filter with a 3dB bandwidth of ±250kHz. This signal contains the phase as well as the amplitude information. To evaluate the phase information, an automatic gain control (AGC) is used for both signal paths. For amplitude detection of the beam signal this AGC must be disabled.

The IF signals are then digitized by an analogue-to-digital converter (ADC) and fed into a DSP & Field Programmable Gate Array (FPGA) unit. For the closed loop control system one output is a digital data stream which controls frequency or phase of the direct digital synthesis (DDS) unit that generates the kicker cavity RF signal. A second output is an analogue data stream which controls the amplitude modulator of the kicker cavity in the synchrotron. For this a digital proportional-integral-derivative (PID) algorithm is implemented on the DSP & FPGA unit which is described below.

In the experiments described in the following one of the normal accelerating cavities served as kicker cavity.

Digital processing part

After the detection of the phase and amplitude the signal is fed into a band-pass filter with an integral element. For dipole oscillations the filter centre frequency (f_{pass}) normally is in the range of f_S and for quadrupole oscillations in the range of $2f_S$. There is no direct current (DC) part in the amplitude detection signal because only amplitude variations shall be measured and an overflow of the integral element part has to be avoided [1]. The filter used is a finite impulse response (FIR) filter. Its equation is

$$x_n = +0.25 z_n - 0.5 z_{n-k} + 0.25 z_{n-2k}$$

with $$k = \frac{1}{2 f_{pass} T_{samp}},$$

z_n as the measured phase and amplitude values respectively at constant time intervals T_{samp}, f_{pass} the centre frequency of the filter and x_n as the output of the filter for a given time. The integral action controller equation is: $$y_n = b \cdot y_{n-1} + K_I \cdot x_n$$

with $y_0=0$, $n>0$, K_I the gain of the controller and 'b' a constant factor (b=1 filter + integrator for quadrupole damping, b=0 only filter for dipole oscillation damping).

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One system for the dipole oscillation damping and one system for the quadrupole oscillation damping were used, respectively, for the experiment because of the two centre frequencies f_{pass} that were needed and the two different action controller constants that had to be set.

EXPERIMENTS AT SIS12/18

Some machine experiments were performed to understand the physics of longitudinal instabilities with a focus on the technical implementation for the damping of longitudinal instabilities [1, 4, 5, 7]. This paper reports on only one of these experiments where it could be shown that the signal processing system prototype for the damping of quadrupole oscillations is successfully working in parallel with the dipole oscillation damping system for the lowest order coupled bunch mode.

Measurement setup

The experiment was performed at the SIS12/18 with the ion species $^{40}Ar^{18+}$ at injection energy (E_{kin}=11.4MeV/u, f_S=3312Hz@U_{RF}=10kV, f_{RF}=1713kHz) and the harmonic number h=8. The beam signal was taken from the Σ signal of a Beam Position Monitor (BPM). In a first approach the centre frequency of the FIR filter was set to f_{pass}=9kHz. Fig. 2 shows the simplified scheme of the data acquisition with the DSP based processing system and the oscillation damping setup by the two closed loops described above. For the lowest order coupled bunch modes it was possible to use the accelerating cavity for damping.

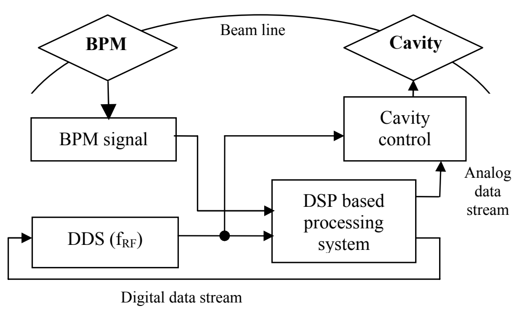

Figure 2: Simplified setup of the data acquisition using the DSP based processing system in the closed loop damping setup for dipole and quadrupole oscillation modes in SIS12/18. (DDS: direct digital synthesis).

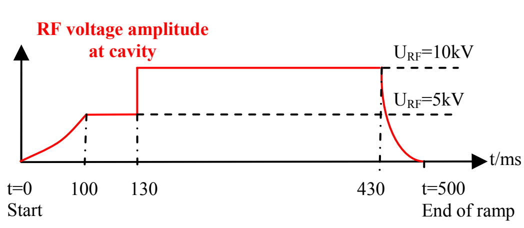

Figure 3: Voltage ramp at the acceleration cavity for the excitation of quadrupole oscillations in the synchrotron SIS12/18.

To induce a defined quadrupole oscillation of the ion bunches a special voltage ramp was used which is shown in Fig. 3. Some time after capturing of the ions the closed loop control system has been switched on and then the quadrupole oscillations were excited by a voltage jump.

Main results

In Fig. 4 (time domain) and Fig. 5 (frequency domain, Hamming window used) the important section of three BPM signals measured under different conditions are shown. The black curve gives a result without any electronic damping system, only Landau damping is active. The red curve gives a result with the closed loop quadrupole damping system active and the blue curve shows a result with the quadrupole oscillation damping system and an additional dipole damping system being active.

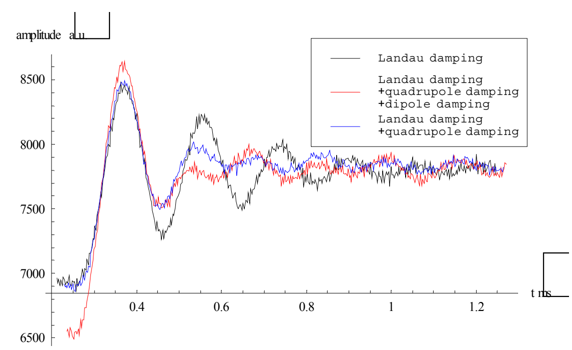

Figure 4: Measured averaged amplitude data of the DSP acquisition system in time domain. Displayed are the first 1.1ms after the voltage amplitude jump. In the caption it is shown which colour represents which damping system state.

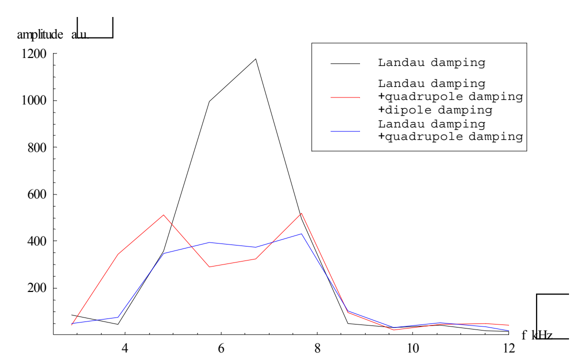

Figure 5: Measured amplitude data of the DSP acquisition system in frequency domain. In the caption it is shown which colour represents which damping system state. To create the spectra the time interval pictured in Fig. 4 has been used (about 1.1ms from voltage jump to the end of the picture).

In Fig. 4 it can be seen that the damping time is only half the damping time of Landau damping if the closed loop damping systems are working. And it is shown that the co-operation of the two closed loop damping systems is possible without negative side-effects.

Fig. 5 shows that only 1/3 of the amplitude of the quadrupole oscillation at its frequency $2f_S$ is left if the damping system is switched on.

Therefore it was shown that the system is able to damp both, coherent coupled dipole and quadrupole oscillations. It has to be emphasized that the artificial excitation in the beam experiment was very strong. In practise intensity induced instabilities will be damped at much lower amplitude levels.

OVERALL SYSTEM DESIGN FOR SIS100

The results presented in the previous chapter made it possible to make an overall system design for a longitudinal bunch-by-bunch closed loop damping system for the synchrotron SIS100 in the FAIR project.

The overall signal processing currently planned for SIS100 can be seen in Fig. 6 as a block diagram [3]. All relevant information for the damping of oscillations of each individual bunch is given by the BPM Σ signal. Variable gain amplifiers provide different measurement ranges which will be set at the beginning of the machine cycle. To have more flexibility, a 'Digital Control Unit' is introduced which may directly forward the information about the measurement range to the variable gain amplifier. Alternatively also the 'DC Transformer' signal can be used but this requires a machine cycle without control for calibration purposes. This current signal can also be used to adapt the control-loop parameters.

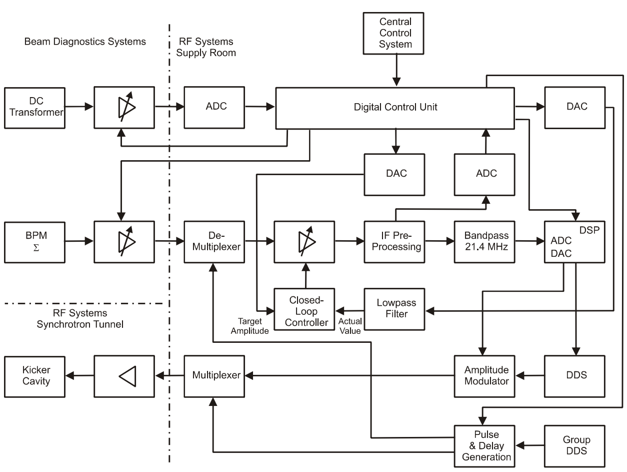

Figure 6: Block diagram of the overall signal processing planned for SIS100. (DAC: digital-to-analogue converter).

The beam signal provided by the variable gain amplifier is now led to a De-Multiplexer which is controlled in such a way that the beam signal of only one bunch is forwarded to the next variable gain amplifier stage (only one of eight signal paths is shown here). This variable gain amplifier stage is needed e.g. for amplitude modulation damping.

The block 'IF Pre-Processing' converts the beam signal into the IF range at 21.4MHz. Because there is only a 'pulsed' IF signal a band pass must be used to reach a steady state and to bridge the revolution time until the same bunch reappears (10kHz bandwidth seems to be appropriate).

The steady state IF signal is then sampled by an ADC and processed by a DSP. Its output signal has to modulate the frequency of the DDS itself and the amplitude modulation requires a dedicated amplitude modulator.

The modulated signal for the special broadband kicker cavity now has to be multiplexed in order to combine the individual signals for the different bunches.

A sophisticated control of the switching times of the de-multiplexer and the multiplexer will be carried out by the 'Pulse & Delay Generation' block which will be controlled by the 'Digital Control Unit'. It will receive its switching time slots by the 'Group DDS'.

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