TRANSVERSE DAMPING SYSTEM AT SIS100

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Abstract

The basic concept and main design features of the transverse damping system at the SIS100 synchrotron are presented. SIS100 with five times the circumference of the current SIS18 accelerator is a part of the Facility for Antiproton and Ion Research (FAIR) which is the next accelerator complex being constructed on the GSI site. The existing GSI accelerators serve as injector for SIS100. The SIS100 synchrotron will provide ion beams of high intensities which can lead to transversal and longitudinal beam instabilities. In order to damp the coherent transverse beam oscillations, a transverse feedback system (TFS) is going to be implemented in SIS100. The TFS presented is a feedback with a real-time digital signal processing for damping of transverse injection oscillations, feedback curing transverse coupled bunch instabilities, and excitation of transverse oscillations for beam measurements and other applications. The data on the bandwidth and gain of the TFS as well as the general description of the central processing unit are presented.

INTRODUCTION

The transverse damping system for the SIS100 synchrotron is a joint project of the Gesellschaft für Schwerionenforschung (GSI) and the Joint Institute for Nuclear Research (JINR). For a large part this project is based on the studies of the transverse damping systems for SIS18 [1] at GSI and for the LHC [2] at CERN. General description of the transverse damper is based on [3, 4, 5].

The SIS100 synchrotron is a part of the Facility for Antiproton and Ion Research (FAIR) which is the next accelerator complex being constructed on the GSI site [6]. It builds on the experience and technological developments already made at the existing GSI facility and incorporates new technological concepts. The existing GSI accelerators serve as injector for SIS100 with five times the circumference of the current SIS18. The SIS100 synchrotron will provide ion beams of high intensities. So, the peak intensities of particles after injection into SIS100 will be about $4 \cdot 10^{13}$ for the proton beam with energy 4.5 GeV and $5 \cdot 10^{11}$ ions for the $^{238}\mathrm{U}^{28+}$ beam with energy 0.2 GeV/u. These intensities can lead to coherent transverse instabilities. For example, the theoretical prediction for the instability rise time $\tau_{\rm inst}$ of the $^{238}\mathrm{U}^{28+}$ beam is about 2.5 ms [7]. Because the acceleration time is bigger than the instability rise time it is necessary to suppress the transverse instability in SIS100 as well as to damp the transverse oscillations of the beam due to injection errors. The coherent oscillations of the beam must be quickly damped to preserve the emittance blow-up. A transverse feedback system will be used for stabilizing the beam. The system will be used also for monitoring of beam transverse dynamics.

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BASIC PARAMETERS

The transverse feedback system (TFS) will operate as a beam feedback system which measures a transverse position (vertical and horizontal) in the pick-up (PU) location and applies a correction signal for damping the oscillations by the kicker (DK) at every turn (see Fig.1). Electronics

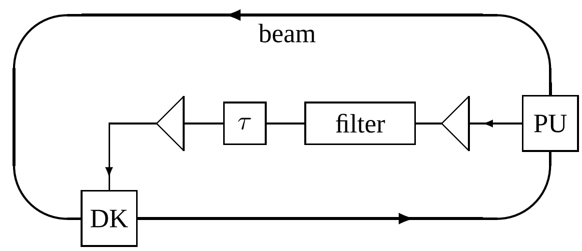

Figure 1: Layout of a transverse feedback system.

for signal processing in the feedback loop is employed in order to synchronize the kick in DK with a particle, the deviation of which is measured by PU, and to obtain different dependencies $f(x)$ between the beam deviation $x[n, s_{\rm P}]$ in PU and the kick $\Delta x'[n, s_{\rm K}]$ in DK at the n-th turn:

$$\sqrt{\beta_{\rm P}\beta_{\rm K}}\;\Delta x'[n, s_{\rm K}] = g \cdot f(x[n, s_{\rm P}])\,. \qquad (1)$$

Here $\beta_{\rm P}$ and $\beta_{\rm K}$ are the transverse betatron amplitude functions in the PU and DK locations; g is the gain of the feedback loop. Power amplifiers with a linear characteristic are normally employed. Hence, the transfer function $f(x)$ of this feedback loop is linear: $f(x) = x[n, s_{\rm P}]$.

If the phase advance from PU to DK is equal to an odd number of $\pi/2$ radians, than the best damping will be for the TFS with the ideal amplifier. In that case the coherent transverse oscillations are damped if the decrement of the oscillations is bigger than the increment of the instability:

$$\frac{T_{\rm rev}}{\tau_{\rm d}} = \frac{g}{2} > \frac{T_{\rm rev}}{\tau_{\rm inst}}\,, \qquad (2)$$

where $T_{\rm rev}$ is a revolution period of a particle in an accelerator and $\tau_{\rm d}$ is the damping time of the feedback [3].

The value of $\tau_{\rm d}$ must be defined also with account of emittance growth due to injection errors. So, the relative emittance blow-up is [5]:

$$\frac{\Delta\epsilon}{\epsilon} = \frac{e_{\rm inj}^2}{2\sigma^2}F_\epsilon\,; \qquad F_\epsilon = \left(1 + \frac{\tau_{\rm dec}}{\tau_{\rm d}} - \frac{\tau_{\rm dec}}{\tau_{\rm inst}}\right)^{-2}, \quad (3)$$

where F_ϵ is a form factor of the emmitance blow-up preservation; σ is an initial RMS beam size; $e_{\rm inj}$ is an amplitude of injection errors of a beam; $\tau_{\rm dec}$ is a decoherence time. It is assumed in (3) that all particles of the injected beam with the emittance ϵ are being injected without an initial angular injection error ($\Delta x'(s_{\rm inj}) = 0$) and the Twiss parameter α at the injection point is $\alpha(s_{\rm inj}) = -\beta'(s_{\rm inj})/2 = 0$.

The maximum value of the form factor $F_\epsilon = 1$ corresponds to $\tau_{\rm d} = \tau_{\rm inst}$ when the maximum emittance blow-up occurs. Therefore, the TFS must provide a minimum value of the form factor F_ϵ for minimizing the effect of the emittance blow-up.

Dependences of the form factor F_ϵ on the instability rise time $\tau_{\rm inst} > \tau_{\rm d}$ are shown in Fig.2 for different values of a decoherence time $\tau_{\rm dec}$ and a damping time $\tau_{\rm d}$.

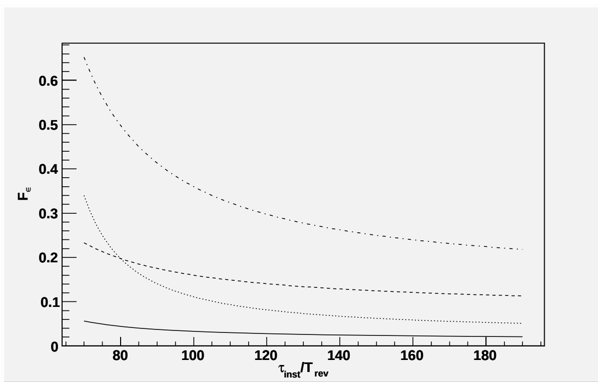

Figure 2: Dependences of the form factor F_ϵ on the instability rise time $\tau_{\rm inst}$. Solid line: $\tau_{\rm dec}/T_{\rm rev} = 300$, $\tau_{\rm d}/T_{\rm rev} = 40$; dashed line: $\tau_{\rm dec}/T_{\rm rev} = 100$, $\tau_{\rm d}/T_{\rm rev} = 40$; doted line: $\tau_{\rm dec}/T_{\rm rev} = 300$, $\tau_{\rm d}/T_{\rm rev} = 60$; dash-doted line: $\tau_{\rm dec}/T_{\rm rev} = 100$, $\tau_{\rm d}/T_{\rm rev} = 60$.

It is clear from the graphic chart in Fig.2 that at nominal beam intensity, when the instability rise time $\tau_{\rm inst}$ is about hundred turns, the form factor F_ϵ of the emittance blow-up preservation is less than 0.16 for $\tau_{\rm d} = 40T_{\rm rev}$ and for $\tau_{\rm dec} > 100T_{\rm rev}$. Hence, $g = 0.05$ will be used for the TFS at the SIS100 synchrotron.

The gain g and the maximum expected injection error $e_{\rm inj}$ yield the maximum deflection $\theta_{\rm max}$ that is required (see equation (1) for $\Delta x' = \theta$):

$$\theta_{\rm max} = \frac{g e_{\rm inj}}{\sqrt{\beta_{\rm P}\beta_{\rm K}}} \,. \tag{4}$$

The deflection θ is delivered by a kicker with an integrated transverse electric or magnetic field or both (stripline kicker) of the following magnitude:

$$\int_0^{l_{\rm K}} (E_\perp + \beta_{\rm r} c B_\perp) ds = \frac{g e_{\rm inj}}{\sqrt{\beta_{\rm P}\beta_{\rm K}}} \frac{m\gamma_{\rm r}\beta_{\rm r}^2 c^2}{q} \,, \tag{5}$$

where $\beta_{\rm r} c$ is the velocity of a particle with the energy $m\gamma_{\rm r} c^2$ and the charge q; $l_{\rm K}$ is the length of a kicker. If $\beta_{\rm P} = \beta_{\rm K} = 19.1\,$m and the electrostatic kicker with $l_{\rm K} = 1\,$m and the aperture of $100\,$mm will be used for the TFS with the gain $g = 0.05$, then the amplitude of a high voltage $U_{\rm K}$ needed for damping oscillations $e_{\rm inj} = 3\,$mm of the $^{238}{\rm U}^{28+}$ beam after injection into SIS100 is

$$U_{\rm K} = 2.4\,{\rm kV} \,. \tag{6}$$

The main instability mechanism that a feedback has to handle is the resistive wall instability. The lowest frequency for this instability is [8]

$$f_{\rm min} = \min|k - Q| f_{\rm rev} \,, \tag{7}$$

where k is an integer; $f_{\rm rev} = 1/T_{\rm rev}$ is the revolution frequency of a particle; Q is the machine tune. For SIS100 we have $f_{\rm min} \approx 0.2 f_{\rm rev} > 20\,{\rm kHz}$.

The highest frequency of a damper system corresponds to the bunch repetition frequency $f_{\rm b}$ [4] or the highest unstable mode of the coasting beam or the long length bunches after injection from SIS18 into SIS100. It was shown in [7] that the whole frequency range up to $20\,$MHz can lead to problems for the beam stability in SIS100. Hence, the bandwidth Δf of the TFS is

$$20\,{\rm kHz} < \Delta f < 20\,{\rm MHz} \,. \tag{8}$$

The data for $U_{\rm K}$ and Δf are the basic parameters of the TFS at the SIS100 synchrotron.

TECHNICAL CONCEPT

Basic variant of the TFS at SIS100 is a traditional feedback circuit with an electrostatic deflector whose electrodes are supplied in a counter phase by classical wideband amplifiers (“push-pull mode”). The similar system is under construction at the LHC (CERN) [2]. The layout of the TFS is shown in Fig.3.

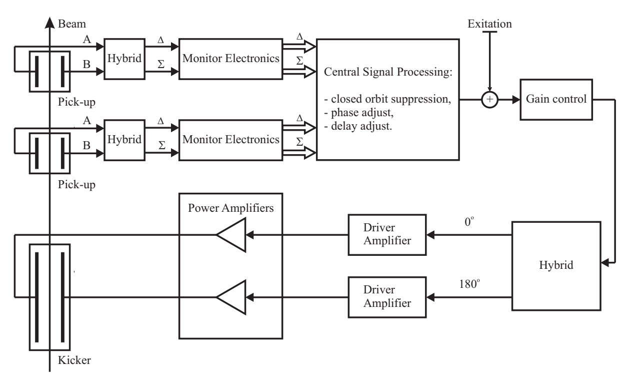

Figure 3: Layout of the transverse feedback system at the SIS100 synchrotron.

The position monitor picks up signals from a bunch or a portion of the coasting beam. These signals are treated first by the monitor electronics and are then passed on to the feedback processing and power electronics which drives the kicker. The synchronization and adjustment of signals, the gating on the consecutive bunches or samples of the coasting beam, the data conversion and the digital signal processing are provided by the Central Signal Processing (CSP) unit. The CSP unit can provide different types of cycles. Each cycle has a set of coefficients that must be adjusted to the working regime of the accelerator and of the feedback system when the accelerator is running.

The Field Programmable Gate Array technology [9] will be used for the CSP unit with the ALTERA device and the analog I/O modules of two-channel 12 bit 125 MSPS analog-to-digital converter and two-channel 14 bit 165 MSPS digital-to-analog converter. The high speed on-board ADC and DAC will be used for producing the output voltage according to the required transfer function.

The CSP unit is clocked at $f_{\rm clk} = 100$ MHz. The variable clock frequency $f_{\rm var} = hf_{\rm rev}$, which is the high order harmonic of the revolution frequency and can be generated by the RF system of the SIS100 synchrotron, must secure the bandwidth of the TFS at the lowest revolution frequency $f_{\rm rev} = 155.8$ kHz for the $^{238}{\rm U}^{28+}$ beam after injection into SIS100. Therefore, $h = 320$ can be used.

The frequency $f_{\rm var}$ is sufficient for operation of the main components of the CSP unit (closed orbit suppression by a notch filter, one-turn betatron phase adjustment, etc.). However, two frequencies $f_{\rm var}$ and $f_{\rm clk}$ must be employed for operation of a programmable delay. The transit time of the signal from pick-ups to the kicker should be matched to the beam flight time by introducing a programmable delay. The dependence of the particle speed on the energy during acceleration leads to the necessity of variable delay changing during acceleration. The programmable delay will be split to the fixed delay and the variable delay adjusting the phase of the signal according to the particle energy.

The delays must be accurate enough so that measurement and deflection are related to exactly the same beam portion within the time resolution of the system. Since the monitor is sensitive to position and the kicker acts on angle, it is necessary to ensure the correct odd multiple of $\lambda/4$ betatron wavelengths between the two devices. This phase adjustment is provided by a virtual pick-up which is generated by combination of signals from two beam position monitors that are shifted on $\approx \lambda/4$ betatron wavelengths between these pick-ups. The phase adjustment allows obtaining the correct odd multiple of $\lambda/4$ betatron wavelengths between the virtual pick-up and kicker.

The control sequence of digital instruction words generated by the CSP unit will be used for adjusting all parameters to the particle energy.

An electrostatic deflector (kicker) and a classical amplifier with tetrodes are proposed for the TFS at SIS100. The deflector and the power amplifier as well as the driver amplifier of the LHC Damper [2] can be used as prototypes for the SIS100 Damper. The amplifier with tetrodes must be closely placed to the deflector in order to match the output circuit of the amplifier with the input impedance of the deflector. Tetrodes are also an adequate choice for the radiation background at SIS100.

The electrostatic deflector is a vacuum tank in length of 1.2 m with devices of a signal input. The stainless steel 304L or 316LN can be used for the tank. Two electrodes in length of 1.0 m, having the form 90^0-sectors with the aperture of 100 mm, are located inside the tank. The electrodes are fixed with the help of ceramic rings that provide the high accuracy of arrangement of the electric axis of a deflector. From the radio physical point of view it is only a capacitor loading for the amplifier. The additional capacitor coupler from each electrode on $50\,\Omega$ loading is installed for reducing the impedance of the deflector and for absorbing the higher order modes induced by the beam. For providing the weak dependence of the deflector's impedance on the frequency from 20 kHz to 20 MHz, the thickness of a wall of the tank should be more than skin depth $\delta(\omega_{min}) = 3.4$ mm of the stainless steel at the lowest frequency 20 kHz. Therefore, the wall thickness of 15 mm can be used.

The kicker with a strip-line and the power amplifier with an output impedance of $50\,\Omega$ will be also studied during R&D stage as an alternative variant of these devices.

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