Simulation of Multibunch Instability

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Longitudinal multibunch instability is a potential source of longitudinal beam quality reduction and beam loss in high intensity synchrotrons [1]. For the SIS high current design parameters of $2 \times 10^{11} U_{238}^{28+}$ ions at injection energy of 11.4Mev/u, with momentum spread $\Delta p/p_0 = \pm 3.5 \times 10^{-4}$ (coasting beam), a coupled bunch instability can be driven by the ring impedances after rf capture.

We use a self-consistent particle-in-cell (PIC) code to simulate the longitudinal motion of the beam under the presence of the rf field and the induced field. All electromagnetic characteristics of the beam environment and space charge are modeled as impedance. For each time step we fast Fourier transform the beam signal and couple it with impedance in order to get the induced field. Each particle is pushed using the local field quantities. Up to 500K macro-particles are usually used in the simulation to reduce the space charge induced simulation noise.

We set rf voltage $V_{rf} = 10kV$, and make the capture slow enough (140ms, due to low initial momentum spread) to be adiabatic. There is an initial rise due to coasting beam instability. In our case space charge impedance $Z_{SC}(p\omega_0)/p$ is $-3.36k\Omega$. Resistive impedance is assumed at h=1(around 215 kHz), and $\frac{Z_R(p\omega_0)}{p}|_{p=1} = 1.5k\Omega$, which is a possible value for SIS whole ring resistive impedance because of some special structures and resistivity between welded chambers in SIS. The simulation results are shown in Fig.1 and Fig.2. A cavity offset can also generate resistive impedance. The shunt impedance (10kΩ) of the bunch compressor cavity [3] operating around 1 MHz is another possible source of coupled bunch instability in the SIS.

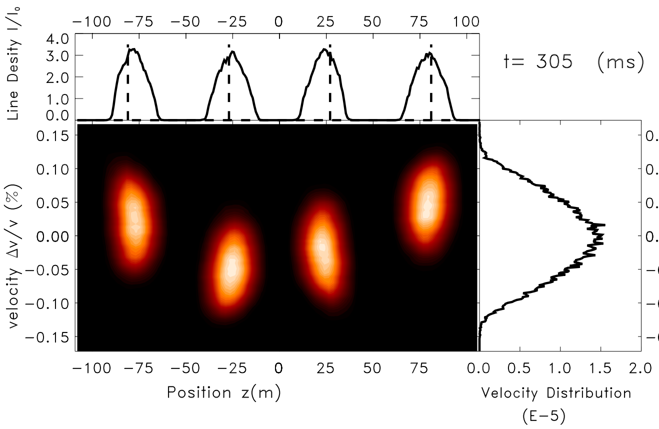

Figure 1: Evolution of the coupled bunch instability for the captured four bunches (total $2 \times 10^{11} U_{238}^{28+}$ ions) at injection energy of 11.4Mev/u in SIS, with momentum spread $\delta p/p|_{FWHM}$ increasing from 1.4×10^{-3} to 2.3×10^{-3}.

Multibunch instability can be damped by the synchrotron frequency spread created by nonlinearity of rf bucket. There is a boundary in the impedance plane, inside which bunches are stable. Fig.3 shows the result

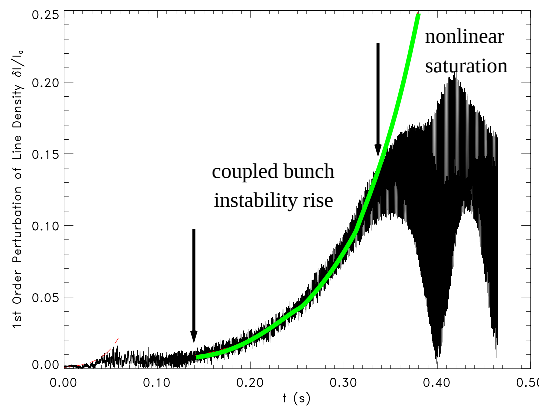

Figure 2: Evaluation of the instability rise time. Time evolution of first order Fourier component of line density.

from simulation and analysis. The stable boundary is obtained from a series of simulation runs. The rise curve is calculated by solving Sacherer's integral problem for the linearized problem.

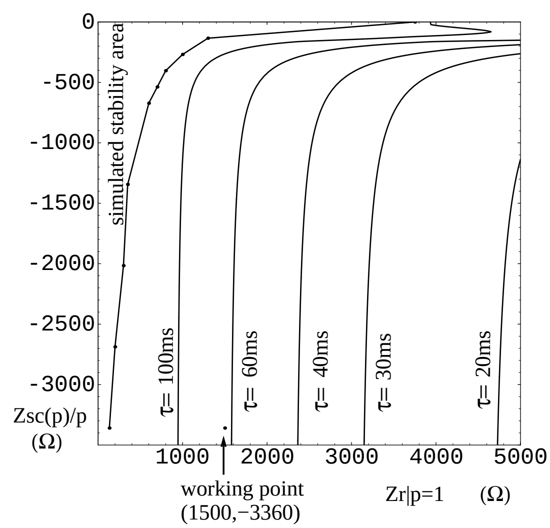

Figure 3: Stability graph in $Z_{SC}(p)/p, Z_r|_{p=1}$ plane.

We plan an experiment in SIS for the coming beam time using one cavity working at h=4 for capturing, and a second cavity with RF off and frequency tuned at h=5 or 7 to create a resistive impedance The coupled bunch mode can be measured and compared with calculations.

References

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[3] K.Blasche et al., Proceedings of the EPAC 98, p. 1347