2 BEAM-DYNAMICS VIEW OF THE FREQUENCY DETUNING

The RF frequency detuning is the first step for the bunch to bucket transfer. In order to realize the frequency-beat between two machines, the RF frequency of the source machine has to be detuned. It means that the particle run at an average radius different by ΔR from the designed orbit R. To make the frequency detuning effective, the radial loop must be turned off just before the frequency detuning begins. Accepting to descriptors the orbit by ΔR for 8mm:

$$\Delta R = 2.4 \times 10^{-5} \, \text{m}$$

The RF frequency detuning at the U28+200MeV/u extraction energy (p = 1.217) is

$$\frac{\Delta f}{f} = \frac{p}{\gamma} = 5 \times 10^{-5}$$

where Δf is the frequency deviation for the frequency detuning, f is the RF frequency, \(1.217\) is the extraction energy (p = 1.217) in the U28+200MeV/u extraction energy (p = 1.217).

The maximum RF frequency deviation of U28 is approximately 7.5 kHz at 1.57 MHz for the U28.

The relative momentum shift is

$$\frac{\Delta p}{p} = p \cdot \frac{\Delta R}{R} \approx 8 \times 10^{-3}$$

where p is the desired momentum of particle, Δp is the momentum shift caused by the frequency detuning.

The frequency detune process must be performed adiabatically. However, the frequency detuning will cause the average radial excursion and relative momentum shift.

3 SYNCHRONIZATION OF TWO MACHINES

The second step for the bunch to bucket transfer is the synchronization of two machines by the frequency-beat method after the frequency detuning is finished at the source machine. For each machine, the TR of the timing system is coupled to RF system. After receiving the timing event (e.g. “Synchronization Begin”) from the timing network, the TRs enable to timestamp the zero-crossing point of the RF signals locally with accuracy better than 1 ns. Besides, the TR at the target machine measures the phase of the harmonic number (n+1) of the RF signal. Then the TR of the target machine sends the packet to the source machine. The data of the packet includes the RF frequency, timestamp of the zero-crossing point, harmonic number and the phase of h+1. All the same time, the source machine sends the packet to the target machine, which includes the same information but the phase of h+1. Both machines have all information so that they could calculate the coarse window.

Within this window, the bunch of particles could be transferred to the target machine with a deviation less than 1°. The source machine makes use of the information of the phase of h+1 to produce a series of announce signals to choose its next RF timing edge, which coincides with h+1 of the target machine. With the help of the coarse window and the announce signals, both machines can trigger their kickers.

3.1 Frequency-beat method

RF frequency-beat method e.g. \(f^{\text{source}} + \Delta f\) and \(f^{\text{target}}\)

The number of SIS100 revolution to realize the synchronization is

$$n = \frac{t_{\text{sync}} - t_{\text{source}}}{f_{\text{source}} - f_{\text{target}}} + \frac{(n + \Delta n) \times f_{\text{source}} - f_{\text{target}}}{f_{\text{source}} - f_{\text{target}}} = \frac{t_{\text{sync}} - t_{\text{source}}}{f_{\text{source}} - f_{\text{target}}} + \Delta n$$

where \(\Delta f\) is the frequency detuning of SIS18 and SIS100, \(f_{\text{source}}\) is the RF frequency of SIS18/ SIS100, \(t_{\text{source}}\) is the best estimation for the timestamps of the zero crossing of point of two RF signals, \(n+1\) equals 1 when \(t_{\text{source}} < t_{\text{target}}\) and equals 0 when \(t_{\text{source}} > t_{\text{target}}\).

3.2 Test setup

We use two MODEL DS345 Synthesized Function Generators with the frequency accuracy of 5 ppm of the selected frequency to simulate RF signals from RF canyels of SIS18 and SIS100. Two FPGA-based cards are responsible for the time/phase measurement, information transmission and coarse window calculation.

3.3 Coarse window and Example

\(t_{\text{sync}} = 1\, \text{MHz} + 100\, \text{Hz}\)

\(t_{\text{source}} = 1\, \text{MHz}\)

\(t_{\text{source}} = 1000\, \text{ns}\)

\(t_{\text{target}} = 27\, \text{ns} \pm 1\, \text{deg/rev}\)

3.4 Test result

The Test run for the synchronization is 10 ms. So the accuracy within this coarse window is better than 1°.

4 SUMMARY

This setup theoretically simulates the synchronization of two machines. It paves the way for the further FAIR bunch to bucket transfer.