First Idea on Bunch to Bucket Transfer for FAIR

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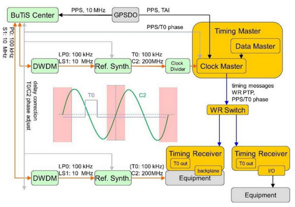
Abstract

The FAIR facility makes use of the General Machine Timing (GMT) system and the Bunch phase Timing System (BuTiS) to realize the synchronization of two machines. In order to realize the bunch to bucket transfer, firstly, the source machine slightly detunes its RF frequency at its RF flattop. Secondly, the source and target machines exchange packets over the timing network shortly before the transfer and make use of the RF frequency-beat method to realize the synchronization between both machines with accuracy better than 1°. The data of the packet includes RF frequency, timestamp of the zero-crossing point of the RF signal, harmonic number and bunch/bucket position. Finally, both machines have all information of each other and can calculate the coarse window and create announce signals for triggering kickers.

1 INTRODUCTION

The bunch to bucket transfer means that one bunch of particles, circulating inside the source machine, must be transferred in the center of a precise bucket and on the desired orbit of the target machine. It is realized by the General Machine Timing (GMT) system and the Bunch phase Timing System (BuTiS).

GMT and BuTiS systems are coupled.



General Machine Timing (GMT) system:

- Time synchronization of timing receivers (TR)
- Distribution of timing events
- Generation of real-time actions by the TRs

Bunch phase Timing System (BuTiS):

- Generation of an ident impulse clock at a rate of 10 µs
- Generation of a 10 MHz sinewave reference
- Generation of a 200MHz sinewave clock

After acceleration to the top energy, the RF flattop, a bunch of particles must be extracted from the source machine to be injected in the centre of a bucket of the target machine without phase and energy error. e.g. Four batches of U^{28+}, each batch has two bunches (h = 2), at 200MeV/µ of SIS18 will be injected into eight out of ten buckets of SIS100 (see Fig. 1).

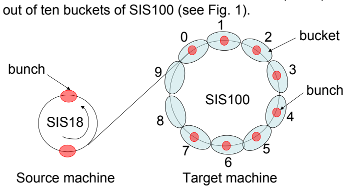


Figure 1: The bunch to bucket transfer of U28+ from SIS18 to SIS100.

2 BEAM-DYNAMICS VIEW OF THE FREQUENCY DETUN

The RF frequency detune 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 particles 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 decenter the orbit by 8mm for SIS18:

$$\frac{\Delta R}{R} \approx 2.4\times 10^{-4}$$

The RF frequency detuning at the U^{28+} 200MeV/µ extraction energy (γ= 1.217) is

$$\frac{\Delta f}{f} = -\frac{\gamma^2-\gamma_t^2}{\gamma^2}\frac{\Delta R}{R} \approx 5\times 10^{-3}$$

where Δf is the frequency deviation for the frequency detuning, f is the RF frequency, γ_t = 5.8. The maximum RF frequency detuning is approximate to 7.5 KHz at 1.57 MHz for the U^{28+}.

The relative momentum shift is

$$\frac{\Delta p}{p} = \gamma_t^2 \times \frac{\Delta R}{R} \approx 8\times 10^{-3}$$

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

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 its 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 1ns. Besides, the TR at the target machine measures the phase of the harmonic number first (h=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. At 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 transfered 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 rising edges, 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. $f_{rf}^{SIS18}+\Delta f$ and f_{rf}^{SIS100}

The number of SIS100 revolution to realize the synchronization is n

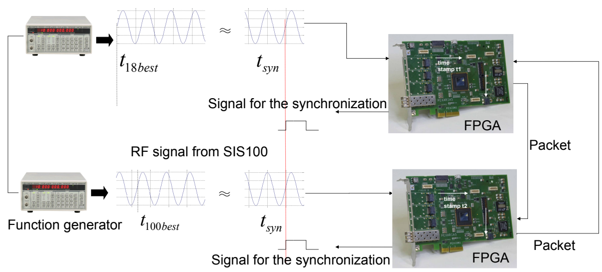
$$t_{100best} + n\times\frac{1}{f_{rf}^{SIS100}} = t_{18best} + (n+\Delta n)\times\frac{1}{f_{rf}^{SIS18}+\Delta f}$$

$$n = \frac{t_{100best} - t_{18best} - \dfrac{\Delta n}{f_{rf}^{SIS18}+\Delta f}}{\dfrac{1}{f_{rf}^{SIS18}+\Delta f} - \dfrac{1}{f_{rf}^{SIS100}}} \qquad t_{syn} = \frac{(f_{rf}^{SIS18}+\Delta f)\times t_{18best} - f_{rf}^{SIS100}\times t_{100best} + \Delta n}{(f_{rf}^{SIS18}+\Delta f) - f_{rf}^{SIS100}}$$

where Δf is the frequency detuning of SIS18, $f_{rf}^{SIS18}/f_{rf}^{SIS100}$ is the RF frequency of SIS18/ SIS100, t_{syn} is the best estimation time for synchronization, t_{18best} ,$t_{100best}$ are the timestamps of zero crossing point of two RF signals, Δn equals 1 when $t_{18best} < t_{100best}$ and equals 0 when $t_{18best} > t_{100best}$.

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 cavities 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

$$f_{rf}^{SIS18} + \Delta f = 1MHz + 100Hz \qquad f_{rf}^{SIS100} = 1MHz$$

$\delta t = \delta t_{18} = \delta t_{100} = 1ns$ Because the RF frequency has the long term stability, $\int \delta f\, df = 0Hz$

$$\delta t_{syn} = \{\frac{(f_{rf}^{sis100})^2 + (f_{rf}^{sis18}+\Delta f)^2}{\Delta f^2}\times\delta t^2 + \frac{2\times[(f_{rf}^{sis18}+\Delta f)\times(t_{18best}-t_{100best})+\Delta n]^2}{\Delta f^4}\times\delta f^2 - \frac{2\times[(f_{rf}^{sis18}+\Delta f)\times(t_{18best}-t_{100best})+1]\times(t_{18best}-t_{100best})}{\Delta f^3}\times\delta f^2 + \frac{(t_{18best}-t_{100best})^2}{\Delta f^2}\times\delta f^2\}^{\frac{1}{2}}$$

Based on these assumptions, the coarse window is14.143µs of the best estimation. The maxmium time for the synchronization is 10 ms. So the accuracy within this coarse window is better than 1°.

$$\delta t_{syn} \approx 14.143\,us \qquad \frac{10ms}{360°} \approx 27.\dot{7}us/\deg ree$$

3.4 Test result

```
=================================================================
The timestamp of RF signal from SIS18 (accuracy to 1ns)
Timestamp: 0x423c51cdc83
GMT:       1970-01-01 01:15:51.0.677369475
-----------------------------------------------------------------
The timestamp of RF signal from SIS100 (accuracy to 1ns)
Timestamp: 0x423c51cdec5
GMT:       1970-01-01 01:15:51.0.677370053
=================================================================
The number of  the revolution of SIS18: 5780
Synchronization time: 5.780000ms
Best estimation timestamp for the synchronization: 0x423c5750ea3
GMT for the synchronization: 1970-01-01 01:15:51.0.683149475
=================================================================
 Uncertainty of the coarse window: 14.143µs
=================================================================
Period of synchronization is : 10000000ns = 10.000000ms
Current timestamp: 0x423c79bf0d8 (1ns)
GMT:             1970-01-01 01:15:51.0.719252184
```

4 SUMMARY

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