BUNCH TO BUCKET TRANSFER SYSTEM FOR FAIR

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Abstract

For the FAIR accelerator complex, synchronization of the bunch to bucket (B2B) transfer will be realized by the General Machine Timing system and the Low-Level RF system. Based on these two systems, both synchronization methods, the phase shift and the frequency beating method, are available for the B2B transfer system for FAIR. This system is capable to realize the B2B transfer within 10ms and the precision better than 1° for ions over the whole range of stable isotopes. At first, this system will be used for the transfer from the SIS18 to the SIS100. It will then be extended to all transfers at the FAIR accelerator facility. This paper introduces the synchronization methods and concentrates on the standard procedures and the functional blocks of the B2B transfer system.

INTRODUCTION

FAIR is aiming at providing high-energy beams with high intensities. Based on the existing GSI accelerators UNILAC and the SIS18 serving as an injector, high intensity ion beams over the whole range of stable isotopes will be accelerated in the new heavy ion machine SIS100 to higher energies. The FAIR new accelerator complex with storage rings will in the full version consist of the SIS100, the Collector Ring CR, the accumulator/decelerator ring RESR and the New Experimental Storage Ring NESR. An additional High Energy Storage Ring HESR serves experiments with high energy antiprotons. The B2B transfer means that one bunch of particles, circulating inside the source synchrotron, is transferred into the center of a bucket of the target synchrotron. For the FAIR project, there are many transfers involving the bunch to bucket (B2B) transfer. E.g. the B2B transfer from the SIS18 to the SIS100, from the SIS18 to the ESR, from the SIS100 to the CR, from the CR to the HESR and later to RESR.

For the FAIR accelerator complex, synchronization of the B2B transfer system will be realized by General Machine Timing (GMT) system [1] and Low-Level RF (LLRF) system) [2].

The main tasks of the GMT system are time synchronization of more than 2000 nodes with nanosecond accuracy, distribution of timing messages and subsequent generation of real-time actions by the nodes of the timing system. The GMT consists of a Data Master (DM), a Clock Master (CM), the White Rabbit (WR) timing network and integrates nodes [3]. The DM schedules actions by broadcasting messages, which will be received and executed by the corresponding node at the designated time.

For the synchronization of LLRF system, the GMT system is complemented and linked to Bunchphase Timing System (BuTiS) [4]. BuTiS is a campus wide clock synchronization and distribution system, locally generating two delay compensated high precision clock signals with a jitter of 10 femtosecond.

Dependent on the BuTiS, the B2B transfer system at FAIR is distinguished from others. For CERN and other accelerator facilities, the B2B transfer system is based on the cavity measured signals [5]. Instead for FAIR, it is based on the driven signals directly derived from the BuTiS.

METHODS OF SYNCHRONIZATION TWO SYNCHROTRONS

For the proper transfer, the phase advance between the bunch of the source synchrotron and the bucket of the target synchrotron must be precisely controlled before the bunch is ejected. The process of achieving the detailed phase adjustment is usually termed "synchronization". There are usually two methods available for the synchronization process, the phase shift method and the frequency beating method.

A short description of the phase shift method is as follows. At a scheduled time well before ejection, the phase of the beam in the source synchrotron and the phase of the bucket in the target synchrotron are measured with respect to the phase of a common central reference signal, which is synchronously distributed to the source and target synchrotrons. Based on the measured phase, the radio frequency (RF) frequency of the source or target or both synchrotrons is modulated away from the nominal value for a period of time and then modulated back so that the phase shift created by the frequency modulation could compensate for the expected phase difference. After the phase shift, the bunches can be injected into buckets. If the RF frequency of the source and target synchrotrons are same, it brings an infinite time frame in ideal situation beginning from the end of the phase shift process, within which the bunches can be injected into buckets at any time. This is the so called synchronization window for the phase shift method (See Figure 1). The phase shift process must be performed adiabatically for the longitudinal emittance to be preserved [6]. But when the target synchrotron has no particles, the phase shift can be done for the target synchrotron without adiabatical consideration (e.g. Phase jump).

The frequency beating method uses the effect of two RF signals of slightly different frequencies, perceived as periodic variations in phase difference whose rate is the difference between the two frequencies. The RF frequency of the

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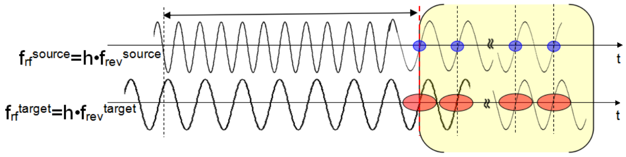

Figure 1: The phase shift method.

source or the target or both synchrotrons is detuned long before the ejection, then the phase difference between the phase of the bunch/bucket and the reference signal is measured. Based on the measured phase, the synchronization is realized when the phase difference of two RF frequencies corresponds to the expected phase difference. Because of the slightly different RF frequencies, there exists the mismatch between the bunch and bucket centers. The requirement for this mismatch is better than 1°, which brings a symmetric time frame with respect to the time of the expected phase difference, this is the maximum synchronization window for the frequency beating method (see Figure 2). During the detune process, the energy of the beam should not be affected.

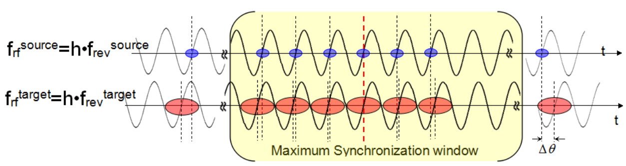

Figure 2: The frequency beating method.

There is a preference to start with the frequency beating method at FAIR, since it is easier to be realized. Many source and target synchrotrons begin the beating automatically, because the ratio of the circumferences is not a perfect integer.

STANDARD PROCEDURES FOR THE B2B TRANSFER

The standard procedures for the B2B transfer system is the same, no matter which synchronization method is chosen. Figure 3 illustrates the standard procedure from the viewpoint of the accelerator cycle. The top part shows the chronological steps of the frequency beating method, according to which the RF frequency is detuned during the acceleration ramp. The bottom part shows the steps of the phase shift method, in this case the phase shift is done after the RF frequency reaches the flattop. The synchronization window must be advanced by the kicker delay in cables, electronics, kicker preparation time and so on. The emergency kickers can be triggered at any time during the acceleration cycle by the machine protection system (MPS), which indicates the status of the synchrotron. The B2B transfer process basically needs to follow six steps (see Figure 3):

1. Announce the B2B transfer and freeze the stabilization system.

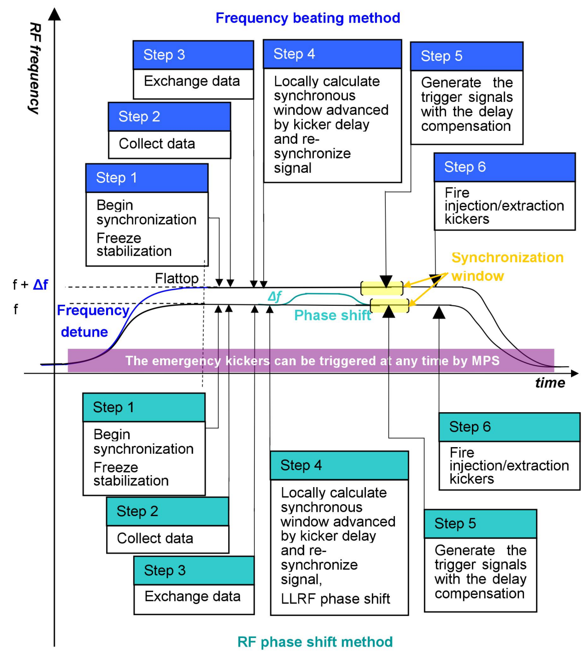

Figure 3: The procedure for the B2B transfer within one acceleration cycle.

2. Collect data from the source and target synchrotrons.
3. Exchange data between source and target synchrotrons.
4. Calculate the synchronization window locally in both synchrotrons with an advance of the kicker delay and re-synchronize RF signal. For the phase shift method, the phase shift process is done.
5. Generator trigger signals for the kickers.
6. Fire the kickers by the kicker electronics.

FUNCTIONAL BLOCKS OF THE B2B TRANSFER SYSTEM

The most important B2B transfer components are specified from a functional point of view. Figure 4 shows the functional block diagram. Two blue boxes show the supply room of each synchrotron.

RF Phase Measurement Module

The RF phase measurement module in each supply room is used to measure the phase difference $\Delta\varphi$ between the reference signal and the dedicated RF signal (group Direct Digital Synthesis (DDS) [2]) of each synchrotron. A reference RF signal is generated locally at each supply room. It is a sine wave, whose frequency is a multiple of the BuTiS T0 and whose reset is triggered by the T0 in order to ensure the synchronization of the reference signals in different supply rooms. The group DDS serves as reference signals for the RF cavities.

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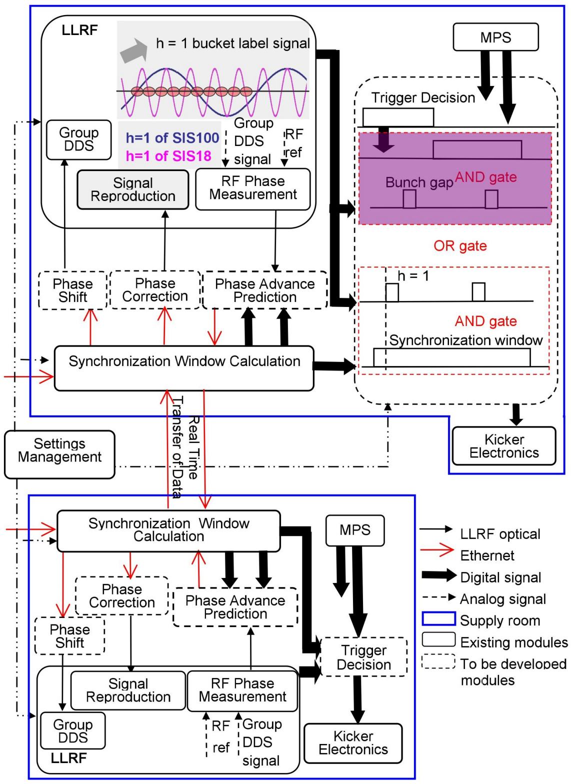

Figure 4: The functional block diagram of the B2B transfer system.

Phase Advance Prediction Module

It makes use of a series of $\Delta\varphi$ measurements from the RF phase measurement module to predict the phase difference after any delay. In addition, it is synchronized to the BuTiS T_0 and C2 [4].

Synchronization Window Calculation Module

This module is responsible for the data exchange between two synchrotrons and the synchronization window calculation. It is also in charge of the start of the synchronization process.

Phase Correction Module

The phase correction module makes use of the phase difference information exchanged between two supply rooms of the synchrotrons to eventually determine a dedicated phase offset and transmits it to the signal reproduction module.

Signal Reproduction Module

The signal reproduction module duplicates the RF signals of the desired harmonic of the other synchrotron and precisely adjusts the phase according to the shared phase information from the phase correction module. It provides the bucket label signal. (e.g. RF h = 1 signal of the SIS100 at the SIS18)

Phase Shift Module

The phase shift module makes use of the the restrictions from the front end controller (FEC) [3] and of the expected phase shift to define a corresponding phase modulation profile. And than it furnishes the group DDS module with phase steps to achieve the expected phase shift.

Group DDS Module

Each cavity is driven by a local DDS unit, cavity DDS [2]. The group DDS receives a revolution frequency ramp from the central control system (CCS) and derives all the needed RF signals of the desired harmonics, one of which is selected as a reference RF signal for the cavity DDS. This cavity DDS receives its phase correction by comparison of the cavity gap signal and the reference RF signal. So the phase of the cavity gap signal is locked to that of the selected reference RF signal. This is realized by the so called the beam phase control [2]. In the case of the phase shift method, the phase shift module may be implemented in an additionally beam phase control for the group DDS module to achieve the expected phase shift.

Real Time Data Transfer

The WR network [1] is responsible for the real time date exchange between two synchrotrons.

Trigger Decision Module

This module is used to produce the trigger signal for the kicker electronics for regular extraction/injection and the emergency extraction.

Kicker Electronics Module

After receiving the trigger signal from the trigger decision module, the kicker electronics produces kicker pulse with the specified width for the regular extraction/injection or the emergency extraction.

CONCLUSION

At first, the B2B transfer system will be used for the transfer from the SIS18 to the SIS100. It will then be extended to all transfers at the FAIR accelerator facility. The B2B transfer system is also available for the standard case of extracting the beam from a synchrotron into a fixed target, like the beam and target collision of the Compressed Baryonic Matter (CBM) experiment.

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