A NEW TIMING SYSTEM FOR THE DUKE BOOSTER AND STORAGE RING*

G. Kurkin#, Budker Institute of Nuclear Physics, SB RAS, 630090, Novosibirsk, Lavrentyev ave, 11, Russia

I. Pinaev, BNL, Brookhaven National Lab, NY 11973, USA

S. Hartman, S. Mikhailov, Y. Wu, FEL Laboratory, Department of Physics, Duke University, Box 90319 Durham, NC 27708 – 0319, USA

Abstract

A dedicated booster synchrotron is being constructed at the Duke FEL Laboratory to provide full energy injection into the main electron storage ring. A new timing system has been developed to coordinate the injection of electron bunches from the linac to the booster, the ramping of energy in the booster, and extraction of bunches into the main ring. The timing system will allow the extraction of any bunch in the booster into any selected bucket in the main ring to provide top-off injection for any of the various operational bunch patterns of the main ring. A new master oscillator has also been developed for the RF system of the booster. The oscillator may be tuned independently or phase-locked to the master oscillator of the main ring. The issues of the soft phase locking process of the new master oscillator are discussed. The timing system and new oscillator have been fabricated and tested and are ready for operation.

TIMING SYSTEM

Since the main Duke storage ring and all its systems are in operation now, and it is desirable not to interfere with its work, we have decided to prepare a new timing system, which will work in the future with the linac, booster and the storage ring. The RF frequencies of both the main storage ring and the booster ring are the same – 178.6 MHz. The master oscillators of both rings are operating at 89.28 MHz – the second subharmonic of RF frequencies, so two signals of the revolution frequencies should be generated in both RF systems. These signals will mark the “zero bucket” in the rings. We decided to produce these signal using LC generators phase locked to the RF frequency rather then by dividing the RF frequency by digital counters. The idea was that a digital counter has no “momentum,” so any miscount is “forgotten” immediately. This miscount will lead to a mess in numbering of buckets in the ring, so all electron current in the ring should be removed and the ring should be refilled anew. In contrast to digital counters, the phase locked oscillator, having a small tuning range and a weak coupling of a high Q-value LC contour with the external circuits, is less sensitive to interference and is more stable in our understanding.

The phase locked oscillators of both rings produce short pulses with a rise time of 1.5 nsec at 9.397 MHz for the booster and 2.789 MHz for main ring. These signals are phased in pairs to their RF reference signals of 178 MHz (see Fig. 1), which are the RF frequencies of both rings and therefore are phased to RF cavity voltages.

The master oscillator of the main ring is controlled only from computer, allowing optimization for the storage ring based free electron laser. The master oscillator of the booster can work in two modes. When the switch Sw. 1 is in position 1, a DC voltage from DAC controls its frequency, so it is possible to work with the booster independently in this mode. If the switch is in position 2, the booster master oscillator is phase locked to the master oscillator of the main ring.

RF frequency harmonic numbers of the rings are 64 for the main ring and 19 for the booster. These numbers are coprime, so if the master oscillator of the booster is phase locked to that of the main ring, positions of bunches in the

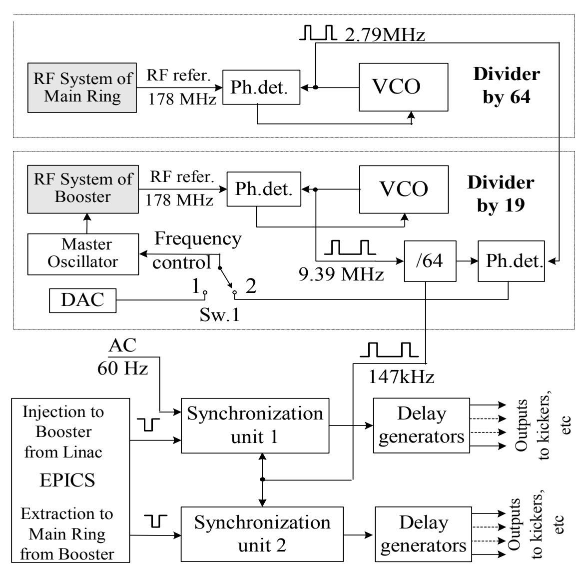

Figure 1: Block-diagram of the timing system.

rings are repeated with the frequency of common divider of revolution frequencies of the rings. This

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#G.Ya.Kurkin@inp.nsk.su

frequency is equal to 2.789/19 = 9.397/64 = 0.147 MHz. A pulse signal of this frequency has been produced by dividing the signal of 9.39 MHz of the booster by 64 using a digital counter. The advantage of this choice is that it is possible to inject electrons into booster, when frequency of its master oscillator is controlled independently, while the main ring may operate at its own frequency. Any pulse of 0.147 MHz signal after proper delay may be used for triggering kickers to transfer a certain bunch from the booster to the main ring. Let us call this certain bunch in the booster a "zero bunch" and the bucket filled in main ring the "zero bucket".

If all delays are increased by one period of RF frequency, the bunch number 1 from the booster will be injected into bucket number 1 of the main ring an so on. It is possible to work out a delay table for injection of any bunch from the booster into any bucket in the main ring. The delay range of the table is equal to one period of 147 kHz. We use VME Digital Delay Generators B950/951 produced by Highland Technologies/Berkeley Nucleonics. They have excellent parameters sufficient for precise triggering of kickers, linac, synchronization signals for oscilloscopes, etc.

The synchronization units pass though the first pulse of 147 kHz after underlying control system generates the corresponding signals. Triggering of injection from the linac into the booster is synchronized also with 60 Hz of the AC mains.

There is a 360° phase shifter in the RF system of the main ring for initial adjusting of the phase of RF cavity voltage in relation to the RF reference so that a bunch from the booster will be injected exactly into the equilibrium phase of the bucket in the main ring. When injecting into the booster, the number of the bucket and the injection phase is adjusted by setting a proper delay for triggering the linac.

Soft Phase Locking procedur

As was mentioned previously, the booster master oscillator can work in two modes. If the position of the switch Sw. 1 is changed from 1 to 2, the procedure of phase locking is started. First a frequency discriminator determines the difference of frequencies of the master oscillators. If this difference is too large, the frequency of the booster master oscillator is tuned until the difference is less than ~ 1/4 of the booster RF cavity bandwidth. The speed of tuning is made low enough to keep the dynamic error of the RF cavity tuner within the required limit.

When the difference is small enough, the phase detector of the phase lock loop may be closed to control the frequency of the master oscillator. However a phase detector has two "zeros": one corresponding to the negative sign of the feedback, the other to a positive sign and therefore is unstable. In order to make a transient of the phase locking predictable, the zero with negative feedback is being waited on and at the moment it comes, the feedback loop is closed. The resulted transient is shown in Fig. 2. Only the "fast" part of the transient of the phase locking process is shown. The following "slow" part will decrease the output voltage (error of the phase lock) almost to zero after ~ 50 msec.

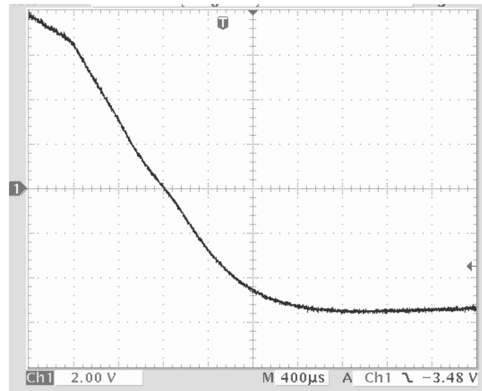

Figure 2: Output signal of the phase detector for booster master oscillator. The phase lock loop is closed at the moment, when signal is crossing zero voltage, while traveling to negative. Scaling of the output is 4V/ns.

The time constant of the transient should be much more than period of the beam synchrotron oscillation in the booster to prevent excessive excitation of the stored beam during the transient. The period of the oscillation is equal to ~10 μsec, the time constant of the transient is ~ 800 μsec, so the condition is met.

Master Oscillator for the Booster

We have used a Surface Acoustic Wave (SAW) oscillator hybrid circuit to produce the new master oscillator for the booster. This SAW oscillator hybrid circuit has very low frequency noise and convenient frequency control in the required range. For better temperature stability in the mode with the independent frequency control, the hybrid circuit is placed into an oven with temperature control. The long term frequency stability of the oscillator is better then 10^{-6}, which is sufficient for booster in the mode.

The hybrid circuit was produced for the Duke FELL by special order. A hybrid circuit of the same type is used in master oscillator of the main ring [1].

At the present time all modules of the timing system are fabricated, all their parameters had been tested and the system is ready for operation.

REFERENCE

[1] G. Kurkin and Ping Wang, "Stable Low Noise RF Source for Main Ring," these proceedings.