Triggers and Timing System for the SSRL 3 GeV Injector*

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Abstract

The electron beam for the SSRL 3 GeV Injector facility is produced in an RF gun, chopped by a stripline deflector to form a 1 nsec long beam bunch, injected into and extracted from a single 358 MHz RF bucket in a 10 Hz booster synchrotron, and injected into a preselected 358 MHz bucket in the SPEAR storage ring. The systems that generate 10 Hz triggers for the linac, beam chopper, and the pulsed and cycling magnets are described.

I. INTRODUCTION

The SSRL Injector facility consists of a 120 MeV S-band linear accelerator and a 10 Hz booster synchrotron designed to provide single bunch filling of 3 GeV electrons for the SPEAR storage ring [1]. The linac beam originates in an RF electron gun [2] driven with power tapped from the waveguide connecting one of the linac sections to its modulated klystron. The gun sources a string of 2856 MHz electron bunches during much of the 1 usec modulator macropulse. A stripline deflector is used to sweep the gun beam past a slit at a rate that only permits 3 of the S-band bunches to enter the linac [3]. These microbunches are accelerated to 120 MeV and are injected into a single 358 MHz bucket in the booster where they are ramped to 3 GeV. The microbunches coalesce into a single bunch before being ejected and transported to a single 358 MHz bucket in SPEAR.

Two classes of trigger timing systems have been implemented to achieve the Injector timing requirements. One system, shown in figure 1, generates 10 Hz triggers for the for the booster resonant magnet power supply system (White Circuit) [4], the focusing and defocusing quadrupole trim tracking supplies, the booster RF gap voltage ramp, and the pulsed ejection septum magnet. This system also provides injection and ejection energy gate signals for the other more precise RF synchronized system, shown in figure 2, used for triggering the linac modulators, beam chopper, booster injection kicker, and booster ejection and SPEAR injection kickers.

II. 10 Hz CLOCK AND ENERGY TIMING

10 Hz Clock and Delayed Triggers

The Injector 10 Hz clock is phase-locked to the 60 Hz line frequency to minimize the impact of power supply ripple on machine stability. The phase-locked loop response is limited to < 1 Hz so that the 10 Hz clock does not track fast line frequency phase jitter. The undelayed 10 Hz clock is used to trigger the White Circuit pulser network and the waveform generators that drive the tracking amplifiers for the two quadrupole families and the RF cavity gap voltage [5]. The frequency stability and timing precision required for these devices is on the order of 0.1% to achieve a comparable level of machine functional stability. This corresponds to a timing stability requirement of order 100 μsec which is easily met with this system.

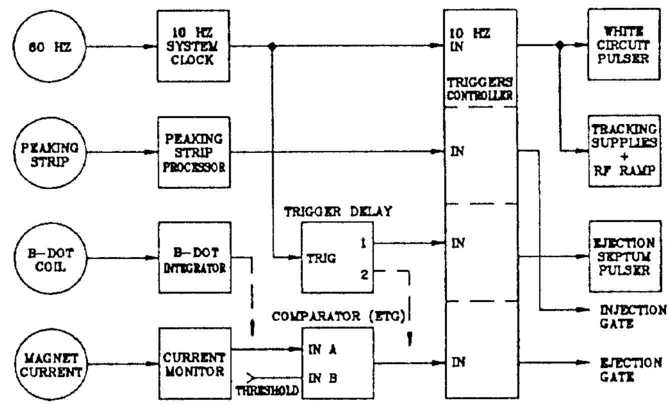

Figure 1. 10 Hz clock and energy gate timing system

The 10 Hz clock signal is delayed by ~80 msec to provide a trigger for the pulsed ejection septum magnet [6]. The magnet pulse width is 17 msec, and the pulse peak timing must be stable to within 100 μsec of the time the booster magnet current reaches the ejection amplitude to maintain 0.1% ejection energy stability. This timing precision over 80 msec is readily achieved with a commercial trigger delay unit; the ejection septum pulser is also stable to this level.

Peaking Strip Injection Energy Timing

Another task for the 10 Hz trigger system is to generate a beam energy-dependent timing gate for the RF synchronized timing system that is used to trigger the linac, beam chopper, and injection kicker magnets. The injection energy acceptance of the booster is ~0.5%; the desired injection energy stability is 0.1% to maximize beam capture and transmission efficiency during ramping. If this stability were to be achieved with a system that generated the injection timing trigger by simply delaying the 10 Hz clock signal, the ring magnet power supply system, which provides a peak current of 630 A at 3 GeV, would have to be accurate to 25 mA at the 25 A injection current.

This stability requirement for the power supplies is relieved by instead deriving the trigger from a permalloy peaking strip located in a solenoid magnet coil situated in the gap of one of the booster dipoles. The peaking strip produces a voltage pulse in the bias coil, which acts also as a sense coil, when the magnetic field in which it is

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immersed changes sign. The bias field is adjusted to exactly cancel the dipole field at the proper injection energy. The Peaking Strip Processor develops a trigger signal from the detected pulse and also sources the coil bias current. The pulse width is inversely dependent on the slope of the changing magnetic field and is ~50 μsec at injection when the magnet current is fully biased. The timing stability is ~2 μsec, well within the 5 μsec tolerance needed for 0.1% injection energy stability.

Ejection Energy Timing

The ejection energy timing gate that is used for generating triggers for the booster ejection kicker and the three SPEAR injection kickers is presently produced by delaying the 10 Hz clock by ~85 msec. This technique requires that the magnet power supply system be stable to 0.1% of its full current capability to achieve that level of ejection energy stability. The consequent timing stability is of order 100 μsec. In practice we achieve this degree of supply stability over the short term (1 or 2 hours), but the supplies needed to be adjusted over longer periods.

To improve the ejection energy stability, we are presently implementing an Energy Timing Generator that detects either 1) the magnet current, or 2) the dipole magnetic field and produces trigger signals when preprogrammed levels are reached. The magnet current is sensed by a high accuracy (< .01%) transductor; the magnetic field is calculated by integrating the the signal from a B sense coil situated in the gap of one of the booster dipoles.

Triggers Controller

All of the above trigger signals pass through a Triggers Controller unit that permits computerized signal on/off control. This unit also automatically switches the triggers for the injection and ejection energy timing gates from their magnet field-and current-derived sources when the White Circuit is cycling to the 10 Hz clock when the White Circuit is off. This permits the linac and kickers to be operated without running the booster magnets and ensures that they will not inadvertently lose triggers, which could be disruptive to stable operation, when the White Circuit turns on or off.

III. RF SYNCHRONIZED TIMING SYSTEM

In order to inject beam into a single 358 MHz bucket in SPEAR, several precise timing events must take place: 1) the three linac klystron modulators the pulsed S-band drive amplifier must be triggered so that the 120 MeV beam arrives at the booster injection point within the 0.1% injection energy window; 2) the injection kicker near the injection point must be triggered so that the incoming beam arrives at the kicker flat-top just prior to the falling edge so that the kicker is fully off by the time the beam completes its first revolution in the booster 445 nsec later; 3) the beam chopper must be triggered within the timing aperture created by the linac macropulse, the injection kicker waveform, and the RF bucket acceptance window in the booster; and 4) the booster ejection kicker and SPEAR injection kickers must be triggered within the ejection

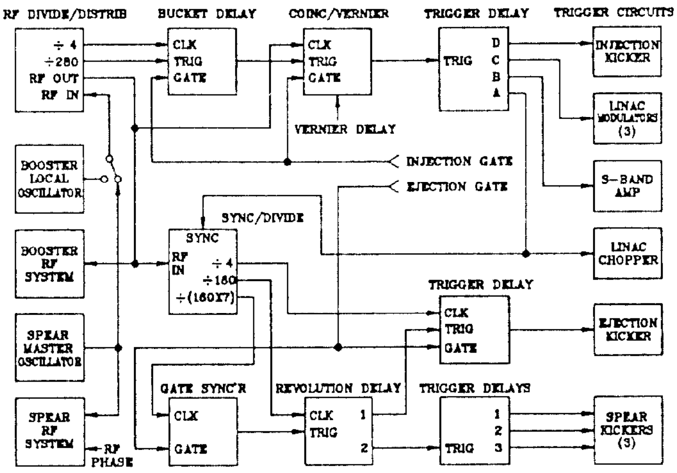

Figure 2. RF synchronized timing system

energy timing gate at a time that will cause the booster bunch to be captured in a preselected SPEAR bucket.

Single Bucket Injection

Two basic system features make single bucket filling feasible: 1) the linac beam chopper creates a short enough (~1 nsec) beam burst with a timing jitter of < 300 psec so that the beam can be reliably captured in single 358 MHz booster bucket; and 2) the booster and SPEAR RF systems are driven by the same 358 MHz master oscillator so that a high level of phase stability between booster and SPEAR buckets is attained.

The second feature guarantees that, because the booster and SPEAR bucket harmonic numbers are 160 and 280 respectively, 7 booster revolution periods will be precisely equal to 4 SPEAR revolution periods. This harmonic relationship ensures that if a booster bucket is extracted at time t_e from the booster, it will hit the same SPEAR bucket as it would if it were extracted at a time $t_e + 7NT_B$, where N is an integer and T_B is the booster revolution period of 445 nsec.

The basic principle of the RF synchronized timing system is thus to 1) create a SPEAR bucket-dependent timing signal that triggers the linac, chopper and injection kicker through appropriate fixed delays; 2) use the chopper trigger signal to reset and synchronize a 358 MHz divider unit that produces timing signals on every 7th booster revolution period; and 3) generate triggers for the booster ejection and SPEAR kickers through appropriate fixed delays from the first such $7T_B$ divider signal occurring within the ejection energy gate.

Bucket Selection Timing

The SPEAR bucket timing signal is obtained by delaying the SPEAR revolution clock signal by integral number of bucket periods. The SPEAR revolution clock is generated by dividing the 358 MHz master oscillator frequency by 280. The computer controlled bucket delay unit counts a programmed number of 89 MHz (358 MHz divided by 4) clock signals; single bucket delay resolution is achieved with a programmable delay line included in the delay unit

[8]. The SLAC designers of this module chose to use the 89 MHz clock, as opposed to 358 MHz, to reduce the need for sensitive high frequency components and packaging methods. The subsequent timing accuracy of this ECL unit is ~500 psec.

The timing accuracy for the beam chopper trigger is increased to the 100 psec level by resynchronizing the output signal from the bucket delay unit with the 358 MHz clock in the Coincidence/Vernier unit [8] using MECL III components. This unit also contains a voltage-controlled varactor diode delay line so that the signal delay can be continuously adjusted over a 4 nsec range. This vernier delay is used to fine-tune the chopper timing so that injected beam arrives within the 300 psec optimal booster RF acceptance window.

The output from the Coincidence/Vernier module triggers a 4-channel programmable delay unit. This unit is used to establish the proper fixed timing relationships between klystron modulator, S-band amplifier, injection kicker and chopper triggers. The relative timing stability requirement between these units is ~10 nsec to achieve 0.1% or better energy spread the linac and to make sure the beam arrives reproducibly at the kicker flat-top [7]; timing jitter on the order of 5 nsec is observed for the modulators and kicker and is caused mainly by the thyratron pulsers.

The critical chopper timing stability of less than 300 psec with respect to the 358 MHz RF drive frequency is maintained by the delay unit and by the MOSFET chopper pulser [3], both which have timing jitters of ~100 psec.

When a different SPEAR bucket is selected, the trigger from the Coincidence/Vernier unit changes by a discreet number of RF bucket periods. The chopped beam timing tracks accordingly with a measured accumulated jitter of ~200 psec (figure 3).

Ejection Timing

If the beam that is injected into the booster were to be extracted the very first time it passed the ejection point, which is a fixed distance from the beam chopper, it would traverse the fixed distance from the ejection point to the SPEAR RF cavity (ignoring the fact that the energy would be wrong!) with the same 300 psec timing precision obtained at the booster cavity. To be captured in the corresponding SPEAR bucket, a vernier delay might be needed so that the beam would arrive within the RF acceptance window. The booster bunch would hit the same SPEAR bucket if it remained in the booster for any integer number of 7 booster revolution periods. Any additional fixed timing delays imposed on the system by component response times or for the purpose of adjusting their relative timing only result in shifting the bucket that will be filled by a fixed number.

The key component in preserving the single bucket timing requirement throughout the ~45 msec between booster injection and ejection is the Sync/Divide unit which performs the synchronized divide-by-seven of the booster revolution period. This unit first divides the 358 MHz clock by 160 using MECL III and ECL components to obtain the booster revolution period. The division is performed by counters that are reset each time the chopper

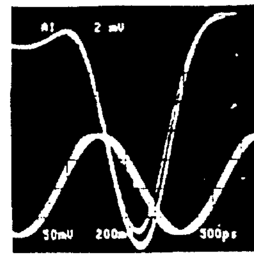

Figure 3. Timing jitter of first turn beam bunch in booster (upper trace) with respect to 358 MHz RF drive (lower trace) is ~200 psec.

is triggered so that the proper synchronization of the divide-by-seven clock and the booster bunch is maintained. When a different SPEAR bucket is selected by shifting the Coincidence/Vernier trigger with respect to the SPEAR revolution clock by a discreet number of buckets, the divide-by-seven clock phase is shifted by precisely the same number of buckets. The timing jitter of the Sync/-Divide output with respect to a synchronizing trigger is measured to be ~200 psec.

The first divide-by-seven clock that falls within the ejection energy timing gate generates triggers for the booster ejection and SPEAR kickers though programmable fixed delay units. Although a 4-channel delay unit identical to the one used for injection timing could have been used here, the booster and SPEAR delay units are located in different buildings for historical reasons. In the case of the booster ejection kicker, this delay is set by cascaded pair of counters: one that counts booster revolution periods for coarse adjustment, followed by a bucket delay unit that provides 2.8 nsec resolution. This timing accuracy is much better than the timing stability of order 10 nsec required for the kickers, also determined by flat-top requirements.

The actual timing precision between the booster and SPEAR buckets is defined by that of the booster beam passing the ejection point, which in turn corresponds to the longitudinal stability of the accelerated booster beam within its own bucket. This precision is better than 100 psec. Vernier timing adjustment is accomplished by adjusting the phase of the 358 MHz drive for the SPEAR RF system using a voltage-controlled 360° phase shifter.

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