A SINGLE BUNCH TRANSFER SYSTEM FOR THE NATIONAL SYNCHROTRON LIGHT SOURCE*

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Introduction

The accelerator system at the National Synchrotron Light Source consists of an S-band 85-MeV linac and three synchrotron rings. The electron beam from the linac is accelerated by the booster ring to 600 MeV and transferred to one of the two storage rings. The smaller of the two rings operates between 300 and 800 MeV emitting photons in the vacuum ultraviolet (VUV), while the larger storage ring operates up to 2.5 GeV and emits photons in the xray spectrum. A system is described for loading the storage rings by filling a single-phase space bunch in the booster ring and transferring it at the end of each booster cycle into a selected bucket in one of the storage rings. By controlling the timing of the transfer on successive transfer cycles, many fill patterns may be obtained.

Initial Operations

Initial operations of the VUV storage ring at NSLS was performed by transferring beam from the booster to the storage ring in 300 to 600 booster ramp cycles of one second each. This resulted in typical beam currents of up to 200 milliamperes with useful lifetimes of up to 5 hours. The rings were operated at the same rf frequency but the transfer timing was not synchronized with the storage ring rotation frequency. This resulted in random filling of buckets. After a typical ten minute injection cycle the bunch to bunch population would vary by as much as 50% (Fig. 1). Transfer timing was triggered from signals derived from the rf frequency which led to a quasi-synched injection into the xray ring, where some buckets would be heavily populated and others being completely empty.

Fig. 1.

Transfer Timing

The method of extraction from the booster for five bunch operation uses a slow orbit deformation during the high energy flat top of the booster dipole

magnet current obtained by powering 4 dipole backleg windings. A fast full aperture kicker extracts the beam through two pulsed septum magnets. The trigger for this magnet is synchronized with the booster magnet current obtained by powering 4 dipole backleg windings. A fast full aperture kicker extracts the beam through two pulsed septum magnets. The trigger for this magnet is synchronized with the booster revolution frequency by dividing the RF frequency by 5. While it is desirable to time the kicker magnetic field to rise between adjacent booster bunches, (19 nanoseconds apart), the limitations of the existing hardware partially destroys one bunch during each transfer. Ripple on the top of the pulse also results in position modulation from bunch to bunch with some of them not completely surviving the trip down the transport line to the storage ring being filled. A total of 18 pulsed magnets are required to do all of the injection/ejection transfers. All three rings are locked to the same R.F. frequency. The harmonic numbers of 5 and 9 in the booster and VUV rings results in designated buckets being in the same time alignment only every 45 RF cycles. In the XRAY ring the harmonic number of 30 results in designated parent buckets in the booster ring for each of the individual X-ray buckets. If the extraction kicker always destroys one bunch the xray ring will then always end up with 6 equally spaced empty buckets.

The booster cycle of one second duration is not an exact multiple of the ring revolution rate but is synchronized with the power line frequency at the start of each booster cycle to minimize the effects of power supply ripple and instrumentation noise.

The Reason for Change

The original method of multibunch transfer had the following limitations and led to the change in the injection system.

1. Limitations on the fast extraction kicker risetime always causes destruction of at least one of the circulating bunches when five bunch booster operation is used. Flat top ripple on the kicker current also leads to each bunch having a different trajectory in the beam transport injection line resulting in poor transfer efficiencies and resultant radiation background levels.
2. The ability to conveniently study the effect of bunch-bunch interactions and instabilities caused by ion trapping and beam wake fields depends on the capability to selectively populate only certain buckets.
3. Experimental measurements of fluorescent decay(1) requires an increase in the space between bunches which can be obtained by populating only a single bucket.
4. Operation of a free electron laser system (2) requires population of only every third bucket.

The New Transfer Timing System

A prototype system was installed to perform synchronous transfer by controlling the time when the electron beam is injected and ejected in the booster ring.

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The 52.88 MHz RF frequency is divided by a counting system using fast TTL logic to obtain the frequencies of RF/5, RF/9, RF/45, and RF/30. These must be generated in the presence of high electrical noise from the pulsed end thyristor power supplies without miscounting for the entire duration of the filling cycle.

The linac injection system (3) uses a 105 kv electron gun delivering up to 1 ampere of beam for up to 2 microseconds at 1 pps. Typical values are 50 milliamperes for 500 nanoseconds, which allows up to five turns of injected booster beam, at rather poor transfer efficiency. To populate only one booster bucket the beam is chopped at the input to the linac by a 10.6 mhz deflection mode electrostatic chopper. This is powered by a 100 watt solid state amplifier driven from the RF/5 signal suitably delayed to coincide with one of the booster rf buckets. To maintain the same charge per booster cycle requires 5 times as much beam into the linac. Beam loading caused by this increased current causes energy changes during each micropulse of about 30 nanoseconds. By passing through an energy analysis slit after the linac the resultant pulses are less than 15 nanoseconds in length. The chopper is usually adjusted for about 7 pulses in this pulse burst.

The current and purity of the single bunch injection can be monitored by a pick up electrodes (Fig. 2) in the booster.

Fig. 2.

Transferring to the VUV Ring

By combining the RF/45 signal with the command to extract, the bunch can be transferred to the same bucket in the VUV ring on repetitive booster cycles. Since the booster bunch can be always made to be on the opposite side of the ring from the kicker when the kicker is pulsed, the problems of fast rise time, time jitter, and extraction efficiency are relaxed.

The choice of particular booster and VUV buckets can be assigned for any injection cycle by reloading the counters during the booster front porch cycle, (prior to each linac injection).

The X-ray Ring

Using the RF/30 and RF/5 signals allows the system to be used for x-ray transfer with the conditions that all possible booster buckets must eventually be used in order to populate all possible x-ray

buckets because of the relationship between ring harmonic numbers.

System Control

The change of injection sequences can be controlled by a local microprocessor through the central computer system (4,5). The ability to select the transfer sequence on a cycle by cycle basis will allow any fill pattern to be used for purposes of machine studies or for the experimental program. A future method of operation will eventually allow automatic topping off the fill to populate all bunches equally.

A block diagram for the synchronous timing system is shown in Fig-3. A local microprocessor connected to the main computer accepts commands from the operator in the control room and converts them into required control signals for the timing system. The commands fall into two groups. The first group of commands selects one of several bunch transfer modes. The second group of commands sets several machine parameters to tune the machine for maximum transfer efficiency.

The high speed synchronous digital timing logic contains counters to divide down rf frequency, shift registers to generate various phase clocks, and multiplexers to select the proper bunch phase for a given transfer mode. The counters provide RF/5, RF/9, RF/30 and RF/45 frequency clocks. These timing clocks are fed into shift registers and the output of shift registers are routed to the microprocessor controlled multiplexers to select a given timing.

FIG. 3. BLOCK DIAGRAM
SINGLE BUNCH SYNCHRONOUS AFER SYSTEM

Fig. 3.

A brief description of how the synchronous timing system works is given here. Prior to the start of a linac injection into the booster, the microprocessor sets the linac rf chopper phase so that only the precalculated bunch, out of 5 possible bunches, is filled in the booster. This calculation is based on the transfer mode selected and the transfer number in real time sequence. At the same time the microprocessor sets all other control signals to select the proper storage ring phase and other delay timings. When the sync timing system receives the transfer request from the master timing system, the sync logic in the sync timing system accepts signals from preselected multiplexers to generate ejection and fast bump timings. At the start of the next linac injection cycle, logic is reset and new control signals are calculated and set by the microprocessor for the next transfer cycle.

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Timing Logic

A brief description of synchronous transfer digital timing logic is given here. A block diagram is shown in Fig. 4. The counter section provides four frequencies by counting down from the master frequency source of 52.88 Mhz. High speed schottky and 'fast' ttl logic integrated chips are extensively used. The four frequencies have physical significance to the geometry of the rings, except for RF divided by 45. The RF/5, RF/9 and RF/30 are revolution frequencies of booster, ultraviolet and x-ray rings respectively. The RF/45 is generated to get a synchronized coincident marker with a given bunch in both booster and VUV rings.

Fig. 4.

The shift registers provide the phase shift into the RF/5, RF/9 and RF/30 signals by clocking at the rf frequency. These phase shifted signals are routed to the multiplexers section for selecting the required phase, and the microprocessor provides the control signals for these multiplexers. The synchronous logic section generates ejection signals from the phase delayed signals. It is done by enabling a flip-flop by the transfer request signal from the master timing system and setting it when the preselected phase delayed signal arrives. Shortly after, this flip flop is cleared to generate signals for the next transfer.

The storage rings bumps are required to be triggered ahead of the ejection signals and, more crucially, should be adjustable to maximize transfer efficiency without changing the phase relationship of the ejection signal. This means a negative delay should be put in to the ejection signal. Actually, the above effect is created by delaying the ejection signal in discrete steps of coincidence frequencies of the booster ring to that of the storage ring, and by generating bump signals from the ejection signal by delaying up to one discrete step in smaller increments. The timing diagram is shown in Fig. 5. The coincidence frequency for the VUV storage ring is RF/45 and for x-ray storage ring is RF/30.

Fig. 5.

Conclusions

The use of the prototype system of the new synchronous timing system has been limited at the present time, mainly for two reasons. (1) Many of the controls in the prototype system are implemented manually and it is cumbersome and time consuming to set machine parameters for different modes of operation. (2) Due to the noise caused by the pulsed magnets bunch slipping due to miscounting between transfers has been observed. More work is needed to eliminate this slipping. In few months, it is expected to install and test the final system with all parameters controlled remotely at the control room and achieve a smooth transfer operation into the storage rings.

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