

RF SYNCHRONIZED INJECTION FROM SPRING-8 LINAC TO NEWSUBARU

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Abstract

This paper confirms the occurrence of RF synchronized injection from SPring-8 linac to the NewSUBARU storage ring. We use a new synchronization method developed at SPring-8, wherein an instantaneous synchronization between NewSUBARU RF (500 MHz) and linac RF (2856 MHz) enables a buckets-to-bucket beam transfer. This is one of the key technologies of top-up operations in a storage ring that uses a linac as an injector. The RF clock and timing trigger signal are sent to the linac from NewSUBARU, and this clock is used to delay units in order to maintain good synchronicity. This works as a standard because it has a system to compensate for transfer-time drift. The arbitrary waveform generator is another key module. It produces a clock 1/32 of that of the linac RF using the NewSUBARU RF clock. With this system, we realized more stable and efficient injection to NewSUBARU.

1 INTRODUCTION

The synchrotron radiation facility NewSUBARU [1] is an EUV and Soft X-Ray light source at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI), at the Himeji Institute of Technology is in charge of its operation, collaborating with SPring-8. The main parameters of NewSUBARU are listed in Table 1. The ring has two operation modes for users. In the 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored, while in 1.0 GeV top-up mode, the beam current is kept at 250 ± 0.15 mA by an occasional injection with the gaps of undulators closed.

The SPring-8 linac is an injector at the SPring-8 accelerator complex, supplying the 1.0 GeV electron beam to the 8 GeV booster synchrotron (SY) and NewSUBARU. Fig.1 shows the layout of the linac, SY

and NewSUBARU. The main parameters of the linac are listed in Table 2. The stabilization and control of longitudinal emittance has been one of the most important R&D projects on the linac. In 2000, installation of Energy Compression System (ECS) reduced the energy spread from 1% to 0.5% (full width) and the energy fluctuation from 0.06% (rms) down to 0.01% (rms) [2]. In 2002, the RF synchronization between SY stabilized the beam charge in one macro beam pulse [3].

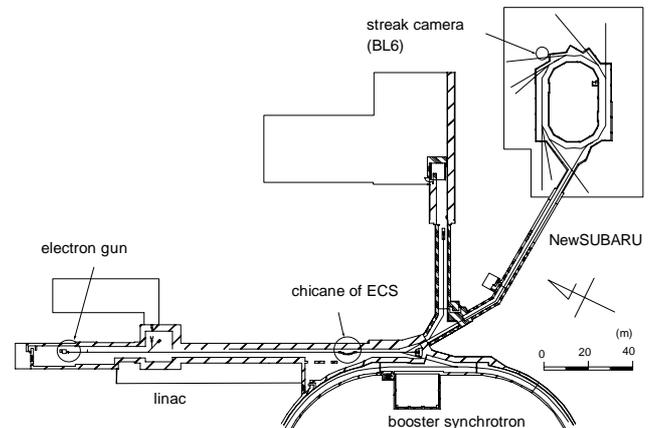


Figure 1: SPring-8 linac, booster synchrotron (SY) and NewSUBARU.

Here we report on the RF synchronization: between NewSUBARU and the linac, which is more important than that with SY because the injection efficiency is one of the most important parameters of the top-up operation. Lower efficiency means high radiation, which would damage the permanent magnets of the undulators. The injection efficiency of NewSUBARU is lower than 80% when the undulator gaps are closed, although at the present this is acceptable because NewSUBARU has no in-vacuum undulator. The RF bucket of NewSUBARU at

Table 1: Main Parameters of NewSUBARU at the injection energy.

Parameters	at 1GeV
RF frequency	500 MHz
RF voltage	110 kV
Synchrotron oscillation frequency	6 kHz
Harmonic number	198
Maximum injection rate	1 Hz
Natural emittance ϵ_x	30 nmrad.
Natural Energy Spread	0.048 %
Natural Bunch length	40 ps (FWHM)

Table 2: Main Parameters of SPring-8 linac with pulse width of 1 ns.

Parameters	without ECS	with ECS
RF frequency	2856 MHz	
Operation rate	10Hz	
Peak current	2 A	
Macro Bunch length	1ns (40ns or 0.25ns is possible)	
Micro Bunch length	10 ps (FWHM)	
Emittance ϵ_x / ϵ_y	31 nmrad. / 58 nmrad.	
Energy Spread	1 %	0.5 %
Energy Stability	0.03 %	0.01 %

the injection point is shown in another report of this proceedings [4]. Even if the bucket size is large enough, the injection efficiency is sensitive to the electron energy from the linac. It is possible that the dynamic aperture of an off-momentum electron is insufficient for an injected beam, which has a large betatron oscillation amplitude. The reduction of the energy spread and the time spread of the linac beam is expected to improve the efficiency. However, simply a reduction of macro pulse width, without the RF synchronization, is not good because it increases the pulse-to-pulse fluctuation of beam charge. The number of micro bunches (according to 2856 MHz) in a macro pulse (1 ns or less) is random. The RF synchronization solved this problem.

2 SYNCHRONIZATION SYSTEM

Fig.2 shows a schematic diagram of the RF synchronization timing system. One of keys of the system is a stable distribution of the 500 MHz master signal. The signal is produced by a master oscillator at NewSUBARU and distributed to the linac control room. A temperature-dependent phase shift of the optic fiber cable is compensated by a PLL feedback, which uses a signal returned along the same fiber [5]. The other key is a synchronus universal counter (SUC) [6], which counts the 500 MHz signal with small jitters. By using SUCs as digital delays and the 500 MHz master signal as a clock, the entire system synchronizes to one master signal. The third key is a use of an arbitrary waveform generator (AWG), which produces a 89.25 MHz signal, 1/32 of the linac RF frequency. By using the 500 MHz master signal as an AWG clock, the synchronization between the master signal and the 89.25 MHz signal is established [7]. The signal is multiplied by 32 and is used as the linac's RF signal.

The macro pulse width is determined by the pulse width of the grid-cathode voltage of the electron gun. A pre-trigger signal, which uses SUC to synchronize NewSUBARU's target RF bucket, is produced at NewSUBARU and sent to the linac. The signal is re-synchronized by SUC and is used to produce the high-voltage pulse. We can select pulse widths of 0.25 ns, 1 ns

or 40 ns but normally 1 ns is selected. The 1 ns macro pulse contains two or three 2856 MHz micro bunches.

3 MEASUREMENTS

3.1 Fluctuation of Beam Timing

We observed the micro bunch structure in a macro pulse, which should be fixed under the RF synchronization, using a streak camera (Hamamatsu C6860) set up at BL6 of NewSUBARU [8]. The camera was operated in double-sweep mode. A 1/6 of the master trigger was used as a fast-sweep trigger, and a trigger signal for the injection pulse septum was used as a slow-sweep trigger.

The camera observed a synchrotron light for 100ms along the slow-sweep axis, which corresponds to about 250 revolutions and is equal to about a half of synchrotron oscillation period. The full range of the fast-sweep axis was selected to be 2 ns, which is 360° in the RF phase of NewSUBARU. The 1 ns macro pulse was injected 20 times and the beam image was accumulated. Three micro bunches synchrotron oscillated in one of NewUBARU's RF buckets, making three lines as shown in the middle image of Fig.3. When the AWG clock was switched to the internal clock, the macro pulse was still synchronized to the RF bucket of NewSUBARU, although the micro bunch structure became random. The clear lines disappeared as shown in the bottom image of Fig.3.

3.2 Injection Efficiency

Injection efficiency into NewSUBARU was measured for different injection phases of NewSUBARU RF. The undulator's gaps were opened. Results of three different cases are shown in Fig.4. With 1 ns macro pulse there was almost no tolerance of the phase for a 100% injection, even when the clocks were synchronized. However when the transverse optics was well tuned, at the best phase we obtained almost 100% injection in 10 out of 10 shots. We can see a micro bunch structure as a step of the injection efficiency, $1/2856 \text{ MHz} = 63^\circ$ apart.

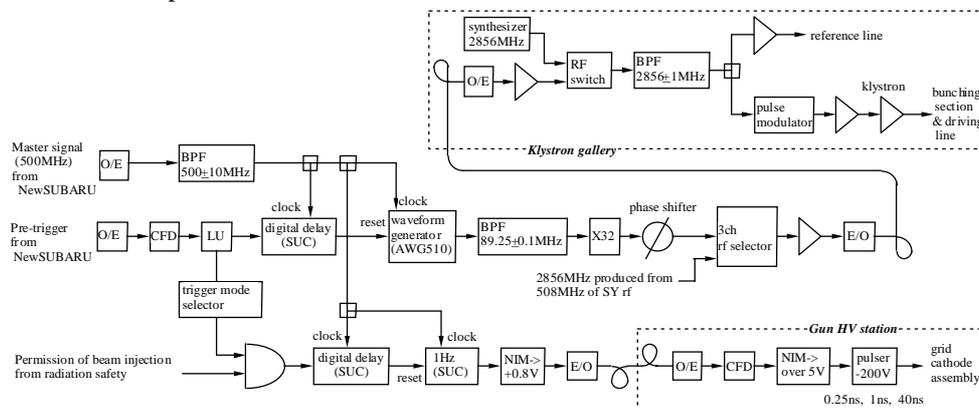


Figure 2: Block diagram of RF synchronization system. The E/O and O/E blocks are electric-optic and optic-electric converters. CFD and LU blocks are constant fraction discriminator and logic units. SUC is a synchronus universal counter.

4 DISCUSSION AND CONCLUSION

We experimentally confirmed the RF synchronized injection from the linac to the storage ring. There have already been some data, which certify the synchronization; however, the data in Fig.3 are the direct proof. We found that an injection with a shorter macro pulse will enlarge the tolerance of machine tuning at the injection. Moreover, we proved that there is no serious problem of the top-up operation using a linac as a direct injector to the storage ring.

One problem of the system was that a shift of the RF frequency of the storage ring changes the RF frequency of the linac and the beam energy. This problem was solved by introducing an easy COD control system, which stabilize the RF frequency of NewSUBARU against the hidden COD [9]. The RF synchronized injection during the user time started in September 2003.

5 ACKNOWLEDGEMENTS

The authors wish to thank Dr. N. Kumagai, a head of the SPring-8 accelerator division, for his continuous encouragement. We also thank the staff of the 1GeV linac, booster synchrotron and the storage ring; especially Dr. Y. Ohashi for his help to construct the timing system. We thank Mr. H. Fukuda of MELCO for his help in developing the COD control system.

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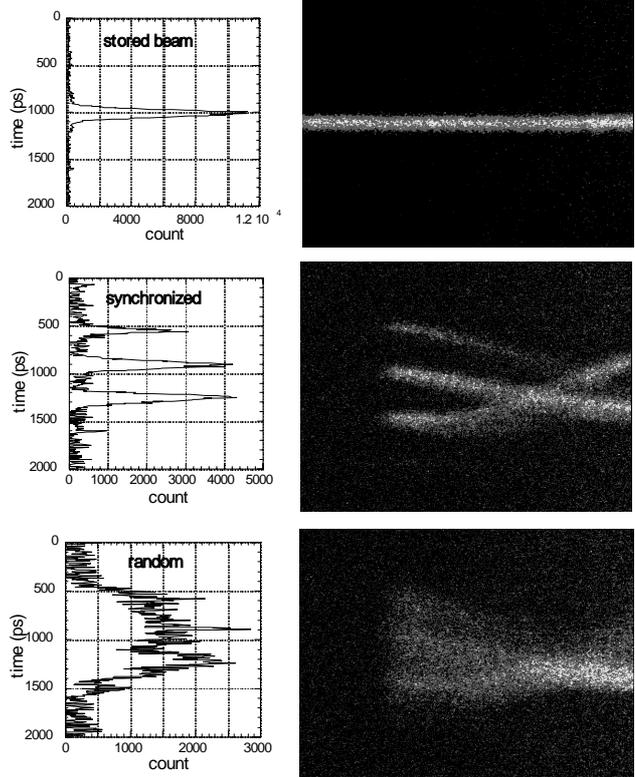


Figure 3: Electron bunch injected into NewSUBARU. The bunch structure was observed by the streak camera set up at BL6 in NewSUBARU. The images at center-right and bottom-right are overlapped images of 20 injections. The full scale of the vertical axis, the fast sweep, is 2000 ps. The full scale of the horizontal axis, the slow sweep, is 100 μ s. The left-hand side plots are time structures at just after the injection.

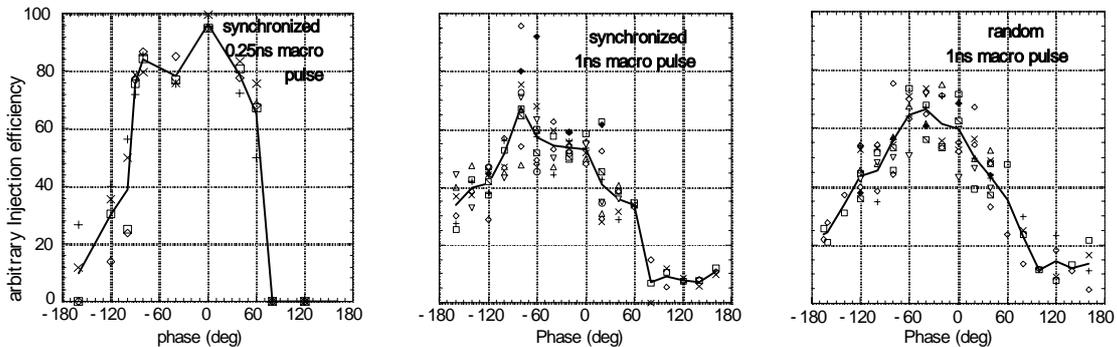


Figure 4: Injection efficiency vs. injection phase of NewSUBARU RF. Points are measured injection efficiency. Lines are averages of 10 shots. The phase of NewSUBARU's RF shifted, while the master signal, the macro pulse timing and the micro pulse did not