PERFORMANCE OF THE ENERGY COMPRESSION SYSTEM AT THE SPRING-8 LINAC

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Abstract

1-GeV electron beams of the SPring-8 linac are injected into the 8-GeV booster synchrotron ring and the 1.5-GeV storage ring “NewSUBARU”. The beam injection into the NewSUBARU was made by one shot every few minutes. The beam energy stability in the linac had to be kept at less than ±0.3%, which is as much as the beam energy acceptance for the NewSUBARU. The energy spread due to the beam loading had to be reduced to increase the beam injection current. For this purpose, an energy compression system (ECS) was installed in the downstream of the linac in 2000. The ECS resulted in beam energy stability of 0.01% rms and reduced energy spread, which consequently realized high current beam injection. This paper describes the RF system of the ECS and the results of beam tests with the ECS.

1 INTRODUCTION

The SPring-8 [1, 2] is one of the largest synchrotron radiation facilities covering from the soft to hard X-ray ranges (0.5-300 keV) and consisting of three accelerators: a 1-GeV linac [3], an 8-GeV booster synchrotron and an 8-GeV storage ring. The storage ring is operated with a beam current of 100 mA. The filling pattern of the storage ring has three modes: single/several-bunch, multi-bunch and hybrid modes. The linac’s electron gun system generates a beam with a pulse width of 1 ns for the single/several-bunch mode and one of 40 ns for the multi-bunch mode.

The 1-GeV linac is also an injector for a 1.5-GeV storage ring “NewSUBARU” [4], which is the another synchrotron radiation facility. Since an energy spread of less than ±0.3% (full width) for a beam with pulse width of 1 ns is required to meet the energy acceptance of NewSUBARU, the incident maximum beam current has been restricted by beam loading of the accelerating structures.

The linac consists of three sections, a 60-MeV pre-injector section, a main accelerating section and two beam transport lines for each ring. The 60-MeV pre-injector section consists of a thermionic electron gun, a bunching section and a 3-m long accelerating structure. The bunched beam is accelerated up to 1 GeV at the main accelerating section, which has 24 sets of 3-m long accelerating structures. The RF for the 3-m long accelerating structures is 2856 MHz; the acceleration mode is $2\pi/3$ for the SLAC type, which is a traveling wave type with a constant gradient. The 1-GeV bunched beams are injected into the 8-GeV booster synchrotron and the NewSUBARU through each beam transport line.

These storage rings have been required to reduce the beam injection time of an intense incident beam and to make the beam intensity uniform in each RF bucket. In order to generate an intense incident beam with a narrow energy spread, we planed to use an energy compression system (ECS). ECS’s have been used at many laboratories since one was extensively studied at the Mainz 300-MeV electron linac (MALAISE) [5]. The two main components of an ECS are a chicane section and an accelerating structure. The chicane section takes the beam through a by-pass transport line and then returns it to its original axis. In this process, the bunch length of the beam is extended along the beam axis according to the electron’s energies. The debunched electrons are then differentially accelerated to minimize their energy distribution at an adequate phase of the RF field in the following accelerating structure. The ECS is utilized not only for reducing energy spread, but also as a beam energy trimmer, which means the output beam center energy can be kept constant.

Energy compression by the ECS in terms of input RF power and phase were calculated by using a simulation code “PARMELA” [6]. The ECS was installed in the downstream of the 1-GeV linac during the summer shutdown period in 2000. The RF processing of the high power RF system for ECS lasted a week. Beam commissioning with the ECS was held in October 2000. Beam operation with ECS has been performed for usual beam injection into both rings since April 2001.

2 CONFIGURATION OF ECS

The linac’s chicane section consists of four rectangular bending magnets, a beam profile monitor using optical transition radiation and a beam slit. These monitors are installed between the 2nd and 3rd magnets where the energy dispersion η is -1 m. As a dispersion-free condition could not be satisfied at the downstream line following the chicane section, two quadrupole magnets for correction were installed in the monitor section of the chicane. The total length of the chicane section is 9.2 m, each bending magnet being 1.7 m in length with a bending radius of 4.1 m and an effective bending angle of 24˚. The compression factor at the chicane section was chosen as 23.8˚/%. The 3-m long accelerating structure of the ECS is the same type as that of the main accelerating section. The ECS compresses the energy spread from ±1.0% (full width) to ±0.3% (full width) for the 1-GeV beam with a bunch length of 20 ps, when the accelerating structure of the ECS holds the electric field strength of 7 MV/m. The beam center energy can be varied by changing the phase of ECS's accelerating structure; the estimated rate is 0.35% per 1˚. However, the minimum energy spread is estimated to remain over the range of 40˚ of the phase. Since the beam energy is sensitive to the phase of the RF fed into the ECS's accelerating structure, this phase should be precisely synchronized with the phase of the beam bunches formed in the bunching section. In the design and construction of the RF system of the ECS, the primary consideration was that the phase of the ECS's accelerating structure should be stabilized during a few weeks. In order to ensure the stability of the center energy within 0.1% (rms) in the present operation, the stability of the phase has to be maintained to within 2˚.

The RF system for ECS is shown in Fig. 1. The master RF signal is fed into a reference 80-MW klystron (TOSHIBA E3712) (H0 klystron), which feeds RF power into the bunching section, the first accelerating structure and a drive line system for 12 sets of 80-MW klystrons in the main accelerating section. This driving RF signal transmits to a 900-W amplifier through a 120-m long phase-stabilized coaxial cable (HUBER+SUHNER SUCOFEED 7/8), which has phase variation of 1.7˚/˚C at 120-m long. An attenuation/phase shifter device following the 900-W amplifier optimizes both the RF power and phase for the 80-MW klystron (M18 klystron) of the final accelerating section. The output RF power of the M18 klystron is divided and supplied to the accelerating structure of the ECS through a power attenuator, a phase shifter and an approximately 20-m long wave guide. It can be assumed that the phase variation in the 120-m long coaxial cable depends on the environment temperature in the klystron gallery. In order to realize the good stability of the driving phase in the 120-m long coaxial cable, we installed a phase lock loop (PLL) in the RF driving system, as shown in Fig. 2. The PLL achieved phase stability of 0.1˚ (rms) during one week, as shown in Fig. 3.

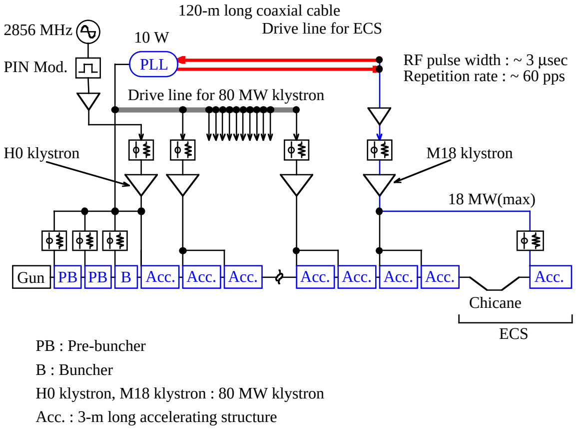

Figure 1: Schematic of the RF system for the energy compression system.

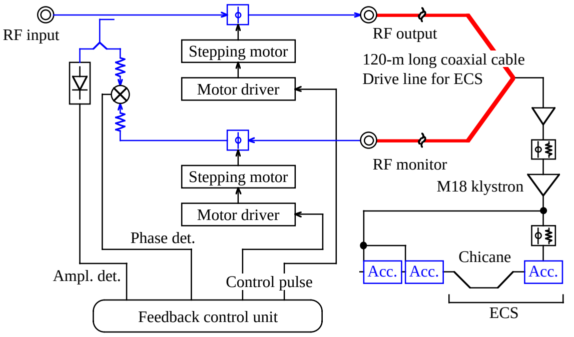

Figure 2: Diagram of the PLL of the driving phase for the accelerating structure of the ECS.

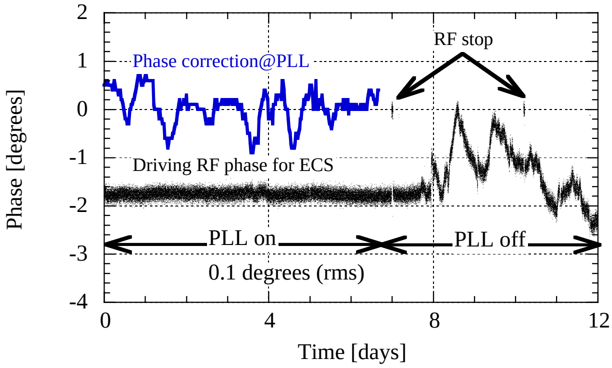

Figure 3: Stabilization of the driving phase in the 120-m long coaxial cable by the PLL.

3 BEAM TEST

The accelerating field of the ECS's accelerating structure was estimated with energy gain of 1-GeV beam. The phase was adjusted to catch the beam bunches on the crest of the RF field. The measurement of the beam energy was carried out by a beam screen monitor (PM3-LS in Fig. 4) installed in a beam transport line between the 1-GeV linac and the 8-GeV booster synchrotron (LSBT), as shown in Fig. 4. The energy dispersion η at the PM3-LS position is -2.5 m. The maximum accelerating field was 13 MV/m, which was agreed with the design value.

1-GeV beams with pulse widths of 1 ns and 40 ns were used in a trial of the energy compression. The reduction of the energy spread as function of the electric field of the ECS's accelerating structure are shown in Fig. 5. The solid line in Fig. 5 is the result of calculation by PARMELA, which shows the minimum energy spread at the electric field of 7 MV/m. The experimental value agrees with PARMELA simulation in terms of the optimum the electric field to the ECS's accelerating structure. The energy spread of ±1.0% (full width) was suppressed to ±0.6% (full width) by the ECS for the beam with pulse width of 40 ns. However, the measured energy spreads are larger than the calculation results. The reason for this difference is considered to be inadequate bunch length after the bunching section.

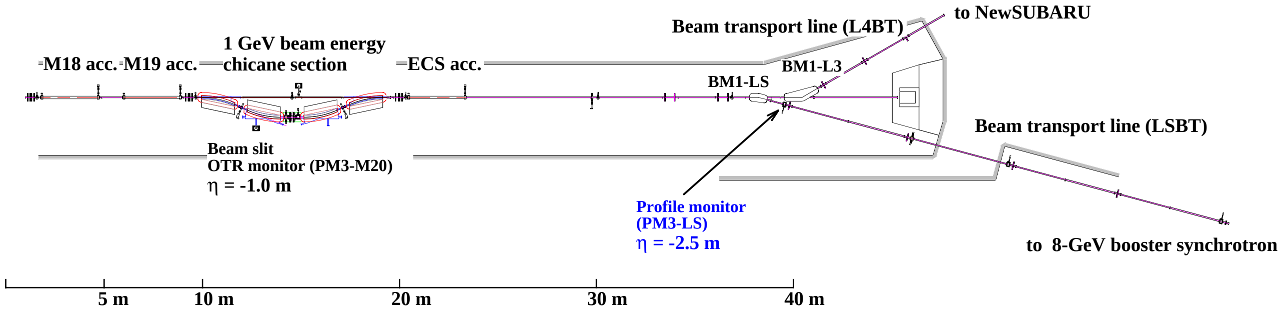

Figure 4: Composition of the 1-GeV energy compression system (ECS), the downstream part of the 1-GeV linac and two beam transport lines, to the 8-GeV booster synchrotron (LSBT) and to the NewSUBARU (L4BT).

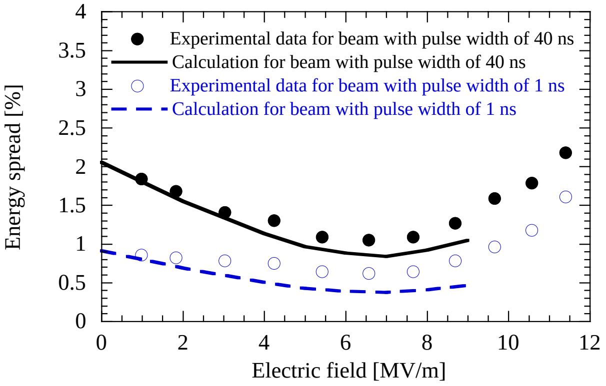

Figure 5: Energy spread with pulse widths of 40 ns and 1 ns as function of the electric field of the ECS's accelerating structure.

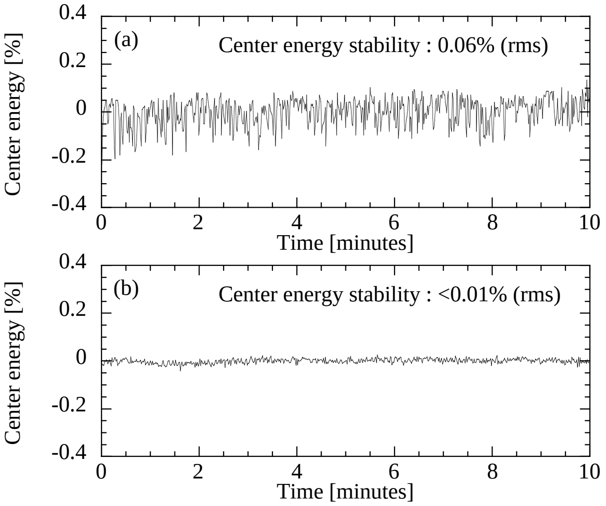

Figure 6: (a) and (b) show the 1-GeV beam center energy fluctuation without and with ECS, respectively.

Since the ECS compressed the energy spread to reduce greatly the beam injection loss, which was caused by the 8-GeV booster synchrotron's beam acceptance, the maximum injection current for the beam with pulse width of 40 ns was increased from the previous 70 mA to 350 mA. It was observed in the case of 350 mA incident beam that the ECS suppressed the energy spread from ±1.8% (full width) to ±0.7% (full width), which was less than ±1.0%, the acceptance of the 8-GeV booster synchrotron.

Beam energy stability was also measured by using the PM3-LS beam screen monitor. The position of the beam profile on the screen staggers horizontally according to its energy. The motion image on the PM3-LS, which expressed the beam energy fluctuation, were taken to a video processor to track the positions of the profile's gravity center. The beam energy fluctuation was reduced from 0.06% (rms) [7] to less than 0.01% (rms) by using ECS, as shown in Fig. 6.

4 SUMMARY

The ECS at the SPring-8 linac has been successfully installed and commissioned. The RF parameters of ECS required for an efficient beam injection into the 8-GeV booster synchrotron were investigated. Thus, the intense beam with ECS can be injected into the 8-GeV storage ring at a short injection time of one-fifth compared with the injection time without ECS. The stabilization of the phase of the ECS's accelerating structure contributed to beam energy stability of 0.01% (rms) or less after the ECS.

5 REFERENCES

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[7] T. Asaka et al., "Stabilization of the RF System at the SPring-8 Linac", to be published in NIMA.