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

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Abstract

A beam energy analyzing system, composed of chicane magnets and beam monitors, was installed at the end of the SPring-8 linac in January 1999. We are now constructing an energy compression system (ECS), which comprises the existing chicane section and a 3-m-long accelerating structure. An analysis of the bunch length and the energy spread of the beam passing the ECS has been performed by the simulation code PARMELA. It is found that an energy spread of ±1.2% (peak to peak) with a bunch length of 10 psec is compressed to ±0.3% (peak to peak). This paper presents the detailed simulation results and the rf system for the ECS.

1 INTRODUCTION

The SPring-8 is a synchrotron radiation facility consisting of a linac, a booster synchrotron and a storage ring. An electron beam is accelerated to 1 GeV by the linac and then injected into the booster synchrotron ring where the beam energy increases up to 8 GeV. The beam is finally accumulated in the storage ring. The linac is able to produce the two kinds of beam pulse widths that are required for the storage ring operation mode. A gun system of the linac generates a beam pulse width of 1 nsec for the single/several-bunch mode and 40 nsec for the multi-bunch mode. In order to realize uniformity of the bunch train in the storage ring, it is necessary to satisfy the requirements of both reproducibility and stability of the beam energy at the linac.

During the summer shutdown period in 1998, the beam energy stabilization was carried out by reducing the rf power and phase drifts by stabilizing the temperature drift of the atmosphere and cooling water [1]. In addition, readjustment was made to the de-Qing efficiency of the klystron modulators [2] for the main accelerating section in order to reduce the PFN voltage fluctuation. As a result, an energy stability of 0.1% (1σ) was achieved [1].

The beam commissioning of the 1.5 GeV synchrotron radiation facility "NewSUBARU" was held in September 1998 for a single bunch operation with an incident beam energy of 1 GeV [3]. Since an energy spread of less than ±0.3% (peak to peak) is required to meet the energy acceptance of NewSUBARU, the incident beam current is restricted by beam loading of the accelerating structures. In order to generate an intense incident beam with a narrow energy spread, we plan to use an energy compression system (ECS). The present beam parameters for the injection into the booster synchrotron and NewSUBARU are summarized in Table 1.

ECS's have been used at many laboratories since one was extensively studied at the Mainz 300-MeV electron linac (MALAISE) [4]. The ECS is utilized not only for reducing energy spread but also for energy stabilization. Furthermore, it is natural to expect that the energy gradient of the beam bunches will be corrected in the multi-bunch operation. The installation will be finished by August of this year. The beam commissioning of our ECS will be held the following month, in September.

Table 1: Beam parameters of SPring-8 linac.

	SPring-8		NewSUBARU
Width	1 nsec	40 nsec	1 nsec
Current	~2 A	~80 mA	~200 mA
dE/E	±0.3%	±0.4%	±0.2%
ε_x 90%	65 πnm rad	31 πnm rad	71 πnm rad
ε_y 90%	43 πnm rad	58 πnm rad	85 πnm rad

2 DESIGN CONCEPT OF ENERGY COMPRESSION SYSTEM

In order to measure the center energy and energy spread at the end of linac, only a chicane section of the ECS was installed and commissioned in January 1999. The chicane section consists of four rectangular bending magnets, a beam profile monitor with a shutter camera, a non-destructive beam position monitor, and a beam slit. These monitors are installed between the 2nd and 3rd magnets where the energy dispersion is 1 m. As a dispersion-free condition could not be satisfied downstream at the chicane section, two quadrupole magnets for correction were installed in the monitor section of the chicane. During normal beam injection into each ring, the 1 GeV beam is always analyzed by this system.

The two main components of the ECS are the chicane section and an accelerating structure as illustrated in Fig. 1. This system makes use of the bunch structure of the beam accelerated to 1 GeV. The chicane section takes the beam through a by-pass line and then returns it to its original axis. In this process, the bunch length of the beam exiting the linac is extended along the beam axis according to the beam's energies. The debunched beam is then differentially accelerated to minimize its energy distribution at an adequate phase of the rf field in the following accelerating structure.

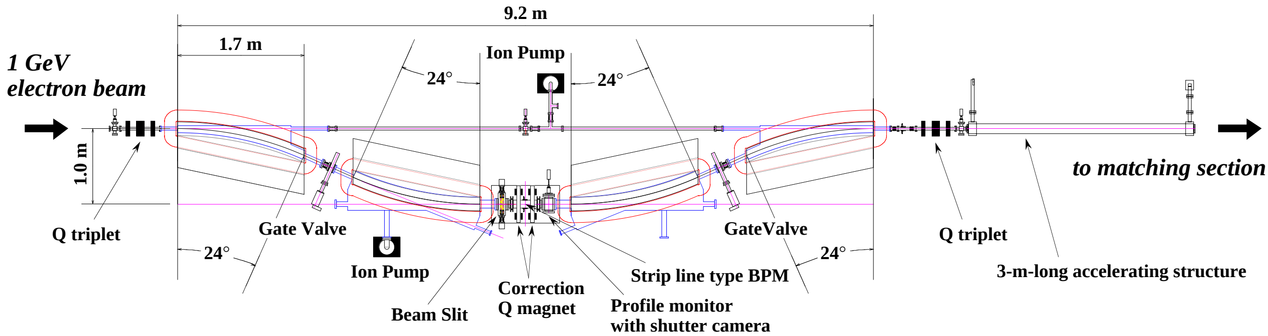

Figure 1: Layout of energy compression system.

The compression factor (Fc) depends on both the initial bunch length at the entrance of the linac and the dispersion at the chicane section. The bunch length is determined by the bunching section at the preinjector. The preinjector is designed to generate a beam pulse width of 1 nsec or 40 nsec at 5 A peak current with a bunch length of 10 psec. For a bunch length of 10 psec, the optimum value of Fc occurs around 25°/%. The dispersion at the chicane section was chosen as 10 mm/%, which corresponds to an Fc of 23.8°/%.

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 physical aperture at the chicane section permits an energy spread of within ±5%. The accelerating structure for the ECS is the same type as that of the regular section. Table 2 shows the parameters of the accelerating structure.

Table 2: Parameters of accelerating structure for energy compression system.

Type	Travelling wave
Electric field distribution	Constant gradient
Resonant Frequency	2856 MHz
Phase shift/cell	$2\pi/3$
Number of cells	81
Shunt impedance	54 MΩ/m
Quality factor	13500
Effective length	2.88 m
Filling time	610 nsec

The energy compression by the ECS in terms of input rf power and phase was calculated by using the simulation code PARMELA. Figure 2 shows the dependence of the compressed energy spread on the accelerating field and the initial energy spread. The maximum accelerating field needs about 8 MV/m to yield a minimum energy spread that is reduced to ±0.3% peak to peak. Using the ECS as an energy tuner, the minimum energy spread is estimated to remain over the range of 40° of the rf phase as shown in Fig. 3. The calculated results of the dependence of the energy spread on the accelerated beam current with or without ECS are shown in Fig. 4.

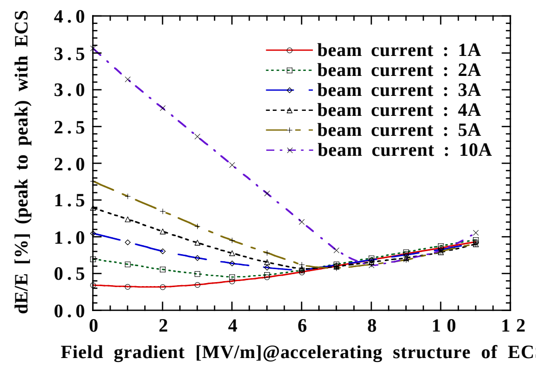

Figure 2: Energy compression as a function of the accelerating field for the bunch length of 10 psec.

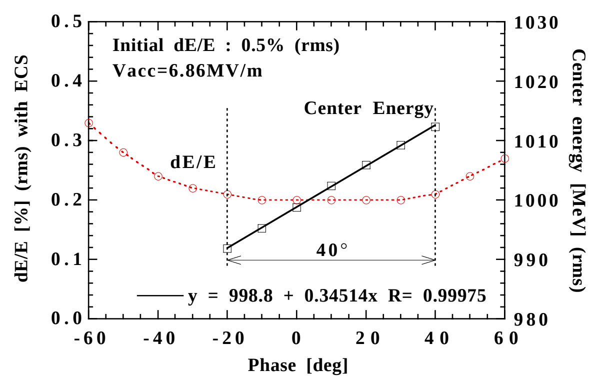

Figure 3: dE/E and center energy as a function of accelerating phase.

When the high current beam has passed out of the accelerating structure of the ECS, the beam induced-voltage remains in the accelerating structure. Since the input rf power fed to the accelerating structure is relatively high, the beam loading effect of the induced-voltage can be neglected. For an incident beam current of 5 A and a pulse width of 1 nsec with dE/E of 1%, the phase shift can be kept below 3° with an accelerating structure input power of 7 MW. In multi-bunch beam for an incident beam current of 1 A and a pulse width of 40 nsec, the effect of the induced-voltage and phase shift can be neglected.

In the present status of the beam injection into NewSUBARU, the maximum beam current is limited to 1 A by beam loading of the accelerating structures. As the compression factor is designed to be 23.8°/%, the ECS can reduce the energy spread from ±1.0 % to ±0.3% (peak to peak) when the bunch length is 10 psec. It is expected that the ECS will permit a maximum incident beam current of 10 A.

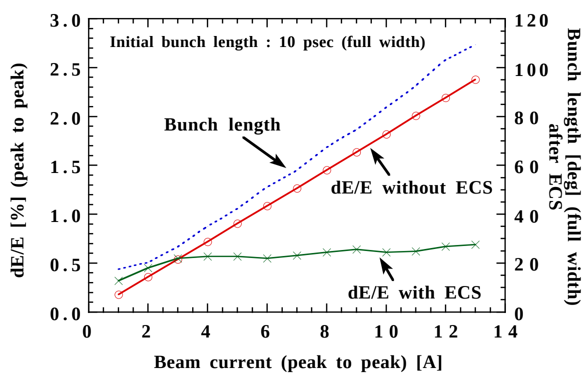

Figure 4: Energy spread dependence on beam current with and without ECS.

3 THE RF SYSTEM

Since the beam energy is sensitive to the phase of the rf fed to the ECS accelerating structure, this rf phase should be precisely synchronized with the phase of the beam bunches formed in the bunching section at the preinjector. In order to ensure the stability of the beam energy within 0.1% (1σ) in the present operation, the stability of the rf phase has to be kept to within 2°.

The rf signal for the ECS is divided into a 7 MW booster klystron (MELCO PV2012), which feeds rf power into the two prebunchers, a 13-cell buncher, and a drive line system for 13 sets of 80 MW klystrons (TOSHIBA E3712) for the main accelerating section (Fig.5). This driving rf signal transmits to a 900 W amplifier through a 120-m-long phase-stabilized coaxial cable (SUHNER SUCOFEED 7/8), which has a phase variation of 1.7°/120m/°C.

An attenuation/phase shifter device following the 900 W amplifier optimizes both the rf power and phase for the 80 MW klystron of the final accelerating section. The output power of the M18 klystron is divided and supplied to the accelerating structure of the ECS through the regulator of a power attenuator, a phase shifter and approximately 20-m-long wave guide.

In order to realize the phase stability of the driving rf, we will install a phase feedback system that can control a phase accuracy of 0.5°. Furthermore, operation of the M18 klystron at higher beam voltage reduces the phase fluctuation as shown in Fig. 6. At present, since a beam voltage fluctuation of 0.2% (1σ) for the M18 klystron is achieved at a beam voltage of 380 kV, the estimated phase stability is 1°.

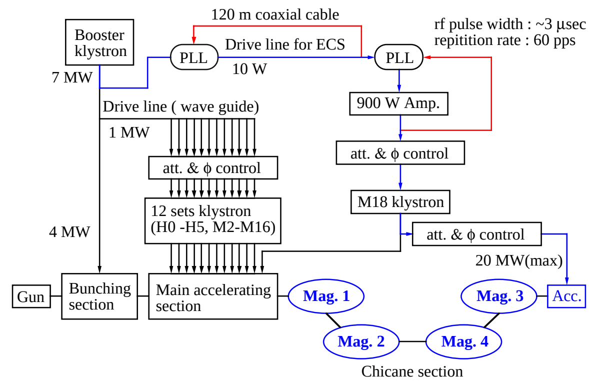

Figure 5: Schematic of rf system for energy compression system.

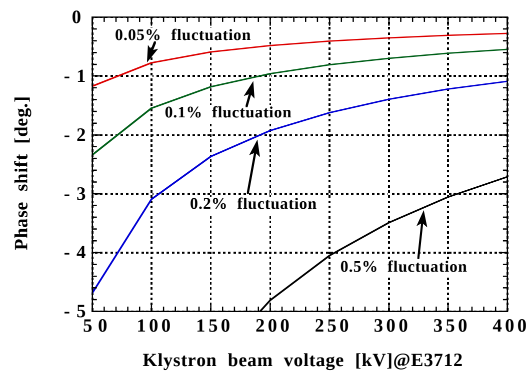

Figure 6: Phase fluctuation of klystron (M18) as a function of klystron beam voltage.

4 CONCLUSIONS

In order to obtain an intense incident beam with a narrow energy spread, an ECS is installed at the end of the 1 GeV linac. It was shown that an energy spread of ±0.3% for each beam current could be achieved with the ECS, which has a compression factor of 23.8°/%. The rf system of the ECS was designed by giving consideration to the stability of the phase, which relates to the bunch structure of the beam. In normal operation, the ECS is expected to be effective not only for reducing the energy spread but also as an energy trimmer, which means the output energy can be kept constant.

REFERENCES

[1] T. Asaka et al., "Stability of the RF System at the SPrin-8 Linac" Proc. of the 18th Particle Accelerator Conference, New York, March 1999, p. 3507

[2] A. Mizuno et al., "Modulators for SPring-8 Linac" Proc. of the 10th Symposium on Accelerator Science and Technology, Hitachinaka, Japan, October 1995, p. 76

[3] A. Ando et al., "Commissioning of NewSUBARU" Proc. of the 12th Symposium on Accelerator Science and Technology, Wako, Japan, October 1999, p. 144

[4] H. Herminghaus and K. H. Kaiser, Nucl. Instr. and Meth. 113 (1973) 189.