# Energy Compression System for 1 GeV Linac

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## 1. Introduction

In order to measure the center energy and energy spread at the end of the linac, only the chicane section of an energy compression system (ECS) was installed and commissioned in January 1999. We are now constructing the ECS, which comprises the existing chicane section and a 3-m-long accelerating structure [1, 2, 3]. 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 was 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.

## 2. Beam Energy Measurement

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 the booster synchrotron and New SUBARU, the 1 GeV beam is always analyzed by this system.

Figures 1, 2 show examples of the measurement results of the center energy and energy spread, where the beam pulse width are 40 nsec for the multi bunch mode and 1 nsec for the single/several bunch mode of the storage ring operation. Since a beam trigger timing is not synchronous with the operation frequency of 2856 MHz, the number of bunches is decided by the buncher section. Since the beam energy is affected by beam loading of the 26 accelerating structures, the variation in the energy spread is caused in case of the intense beam current and the beam pulse width of 1nsec or below.

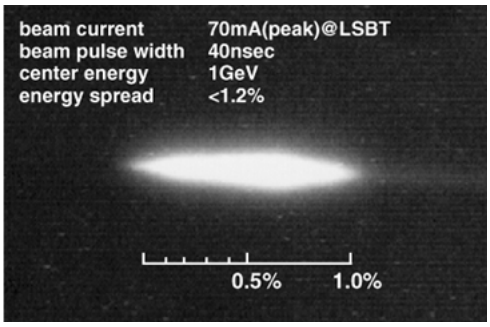


Fig. 1. The energy spread at the 40 nsec beam pulse width and 70 mA beam current (peak to peak).

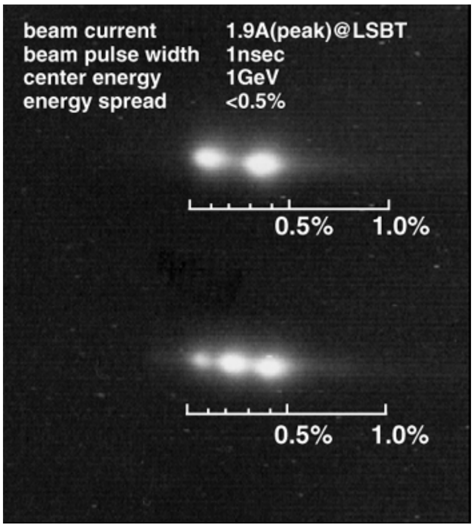


Fig. 2 The energy spread at the 1 nsec (case of 2 and 3 bunches) beam pulse width and 1.9 A beam current (peak to peak).

The relation between the energy gain $E_{(t)}$ and the beam current per bunch $I$ is expressed as

$$E_{(t)} = \sqrt{P_k R_S \ell (1-e^{-2\tau})}$$

$$\frac{R_S I \ell}{2} \left\{ \frac{2\tau e^{-2\tau}}{1-e^{-2\tau}} \frac{t-t_F}{t_F} - \frac{1-e^{-2\tau\left(\frac{t-tF}{tF}\right)}}{1-e^{-2\tau}} \right\}$$

$$t_F \le t \le 2t_F$$

where $P_k$, $R_s$, $\ell$, $\tau$ and $t_F$ are the input power, the shunt impedance, the effective length, the attenuation parameter, and the filling time of a structure [4].

From the above equation, the center energy differential at the bunch number for beam pulse width of 1 nsec is calculated as Fig. 3, which agrees with results of the measurement value (Fig. 2).

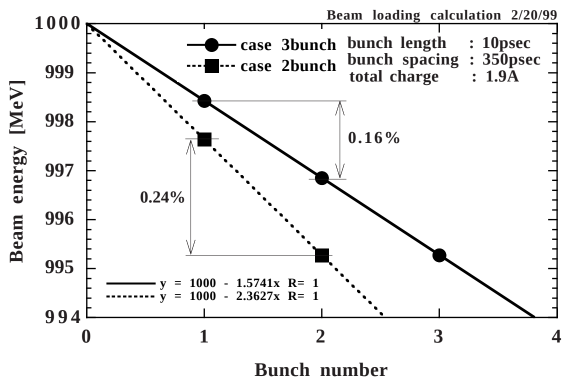


Fig. 3 Energy gain dependence on beam current.

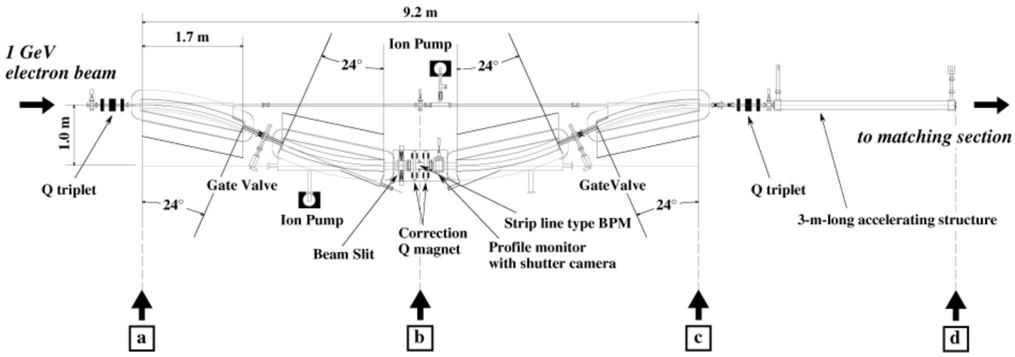


Fig. 4. Layout of energy compression system.

## 3. Design Concept of ECS

The two main components of the ECS are the chicane section and an 3-m-long accelerating structure as illustrated in Fig. 4. 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.

The compression factor (Fc) depends on both the initial bunch length at the entrance of the linac and the dispersion at the chicane section [1]. 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.

The energy compression by the ECS in terms of input rf power and phase was calculated by using the simulation code PARMELA. Figure 5 shows some examples of calculations of the energy compression and debunching processes. Figure 6 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. 7. The calculated results of the dependence of the energy spread on the accelerated beam current with or without ECS are shown in Fig. 8.

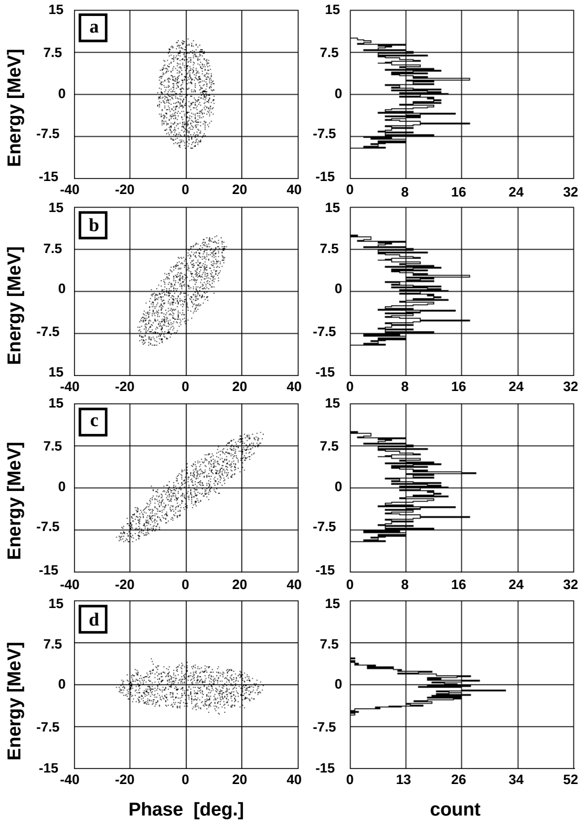


Fig. 5. Energy compression and debunching process.

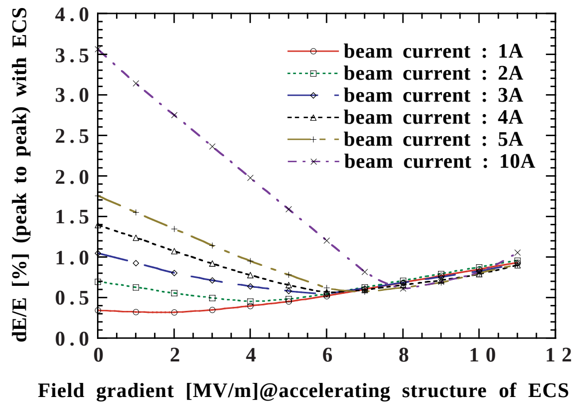


Fig. 6. Energy compression as a function of the accelerating field for the bunch length of 10 psec.

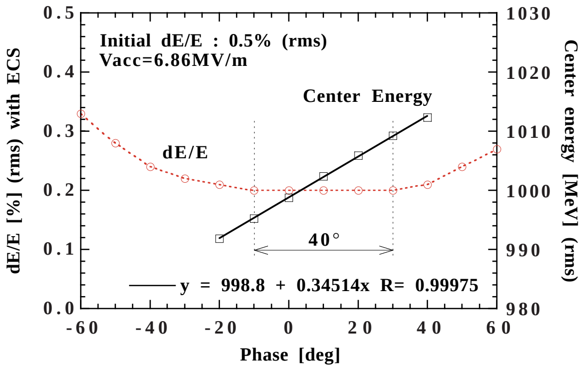


Fig. 7. dE/E and center energy as a function of accelerating phase.

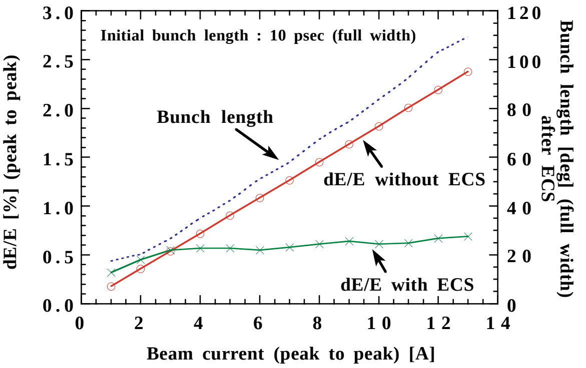


Fig. 8. Energy spread dependence on beam current with and without ECS.

When the high current beam has passed out of the accelerating structure of the ECS, the beam induced-voltage remains in the accelerating structure. The net accelerating voltage $V_a$ and phase shift $\phi$ acting the charge $q$ is

$$V_a = V_g \cos\theta_g - n\, k_0 q$$

$$\phi = \tan\left(\frac{n\, k_0 q}{V_g}\right)$$

(n = 1 : 1st bunch)
(n = 2 : 2nd bunch, 3rd bunch, ⋯)

where $V_g$ and $\theta_g$ are the generator voltage, the phase of the generator voltage component before the charge crosses the structure. The loss parameter k0 relates the quantity $R_s/Q = V_a^2/\omega W$ and is obtained as

$$k = \frac{\omega}{4}\frac{R_s}{Q} \quad .$$

From the above equation, Fig. 9 shows calculation results of the phase shift at the accelerating structure for ECS.

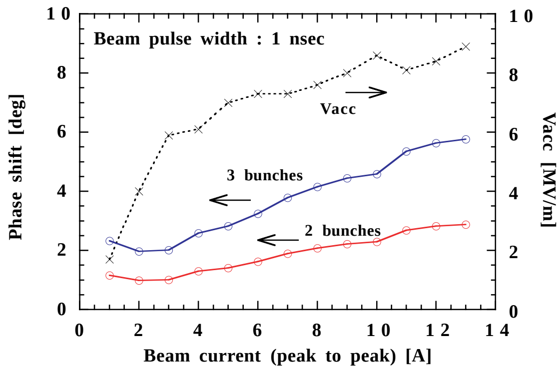


Fig. 9. Phase shift dependence on beam current (beam pulse width of 1 nsec).

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 New SUBARU, 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.

## 4. Summary

The ECS is utilized not only to reduce 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 multi-bunch operation. The installation will be completed by August 2000. The beam commissioning of the ECS will be held the following month, in September.

## References

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[4] P. B. Wilson, "High Energy Electron Linac: Applications to Storage Ring RF Systems and Linear Collider", SLAC-PUB-2884, February 1982.