SUB-PICOSECOND COMPRESSION EXPERIMENT BY VELOCITY BUNCHING IN THE S-BAND PHOTO-INJECTOR AND LINAC

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Abstract

The velocity bunching is one of the electron bunch compression methods, which was proposed by L.Serafini, et al. in 2000. We have carried out the velocity bunching in the Mg photo-cathode RF injector and the S-band Linac at the Nuclear Engineering Research Laboratory, the University of Tokyo. The bunch length is measured by the femtosecond streak camera. We have achieved the shortest bunch length of 0.5 psec (FWHM), the average length of 1.3 psec (FWHM) and the fluctuation of 0.4 psec (rms) for 1 nC/ and the injected RF phase of the zero-crossing. The results are consistent with the numerical analysis, which was done by PARMELA simulation code.

1. INTRODUCTION

The velocity bunching, which is one of the electron bunch compression method, was proposed by L. Serafini in 2000[1]. The compression scheme is based on the rectilinear compressor. Since the relevant compression magnet is not used, several harmful Coherent Synchrotron Radiation force effects can be avoided.

At Nuclear Engineering Research Laboratory, the University of Tokyo, an S-band linac with an Mg photo-injector (18L) is utilized for experiments of radiation chemistry as such as the chemical reaction of water. To realize the high time-resolution in order of sub-picosecond, the chicane-type magnetic compressor is normally used[2,3]. Although the chicane-type compressor has the ability to produce short bunch enough, we are planning this new compression method.

Normally two accelerating tube are used for the complete scheme of velocity bunching as shown in SPARC project[4], because the energy of compressed beam in the first tube is extremely low. Therefore, the electron bunch from the photo-injector is compressed in the first linac and accelerated in the second linac. Unfortunately 18L has only one accelerating tube. However, Helmholtz coils to suppress the emittance growth due to the space-charge effect are located around the linac. Thus, we have demonstrated the velocity bunching with concentrating the verification of compression scheme using one accelerating tube and Helmholtz coils.

2. THEORY

As mention above, the velocity bunching is based on the rectilinear compression scheme. The bunch is injected just after the zero phase of RF in the accelerating tube. Consequently, it is compressed due to the velocity-difference between the head and tail of the bunch with slipping backward to the RF crest. Owing to the magnetic field of the solenoid surrounding the accelerating tube, the emittance growth due to the space-charge effect at the low-energy region is avoided to realize the Brillouin flow. Consequently, the electrons in the bunch do not cross over radially.

To calculate the compression factor it must be consider that the Hamiltonian is an invariant of the motion[1]:

$$H = H_0$$

where

$$H = \gamma - \beta_r\sqrt{\gamma^2 - 1} - \alpha\cos\xi$$

$$H_0 = \gamma_0 - \beta_r\sqrt{\gamma_0^2 - 1} - \alpha\cos\Psi_0$$

Taking the initial conditions of the injection phase and energy, the compression factor C has been evaluated as follows:

$$C = \frac{\delta\Psi_0}{\delta\xi_{ex}} = \frac{2\delta\Psi_0\left|\sin\xi_{ex}\right|}{\sqrt{\delta\Psi_0^4 + \left(\frac{1}{\alpha\bar{\gamma}_0}\frac{\delta\gamma_0}{\bar{\gamma}_0}\right)^2}}$$

where $\delta\Psi_0$ is the initial bunch width, $\delta\xi_{ex}$ the final bunch width (at extraction phase), ξ_{ex} the extraction phase, γ_0 the initial beam energy, $\delta\gamma_0/\gamma_0$ the energy spread. Figure 1 shows the contour plot for 18L parameters. The vertical axis indicates the beam energy γ.

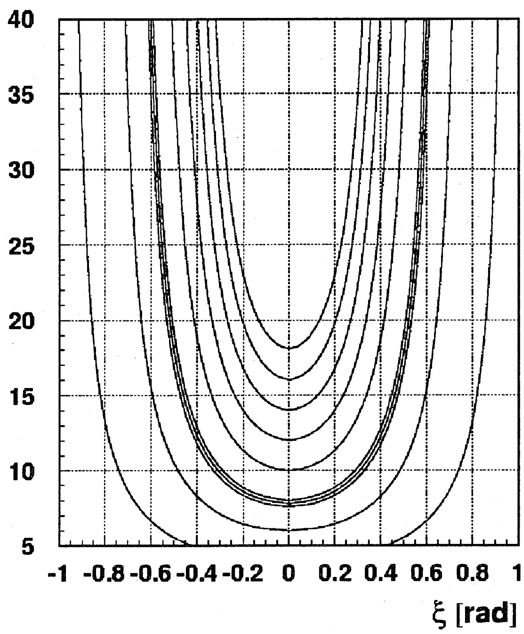

Fig. 1 Contour plot for 18L parameters.

3. EXPERIMENTAL SETUP

Figure 2 shows the schematic view of experimental setup. The electron beam is generated from the photo-injector which is driven by the third harmonics of Ti:Sapphire laser pulse. The electron bunch with charge of 1 nC is accelerated up to energy of 4 MeV approximately. The beam exited will be focused by the solenoid magnet then injected in the accelerating structure. It continuously is accelerated by the 2856 MHz frequency of traveling wave. The aero gel with its index of 1.015 and thickness of 1 cm is used as the Cherenkov radiator. The energy threshold is 3.0 MeV. The Cherenkov radiation emitted by the electron bunch moving in the Aerogel material, reflected by a flat mirror, converged by 2 lens and finally reflected again by the other mirror into the femtosecond streak camera through the band pass filter.

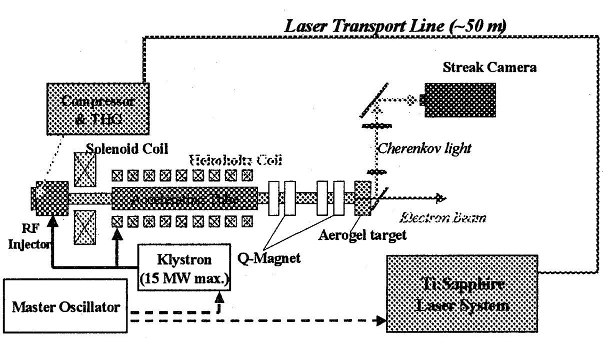

Fig. 2 Schematic view of experimental setup.

The amplitude of magnetic field by Helmholtz coils is fixed to be 300 Gauss.

4. RESULTS

Figure 4 shows a typical streak image at zero-crossing injection. The bunch width is measured to be 0.5 psec at FWHM in the image.

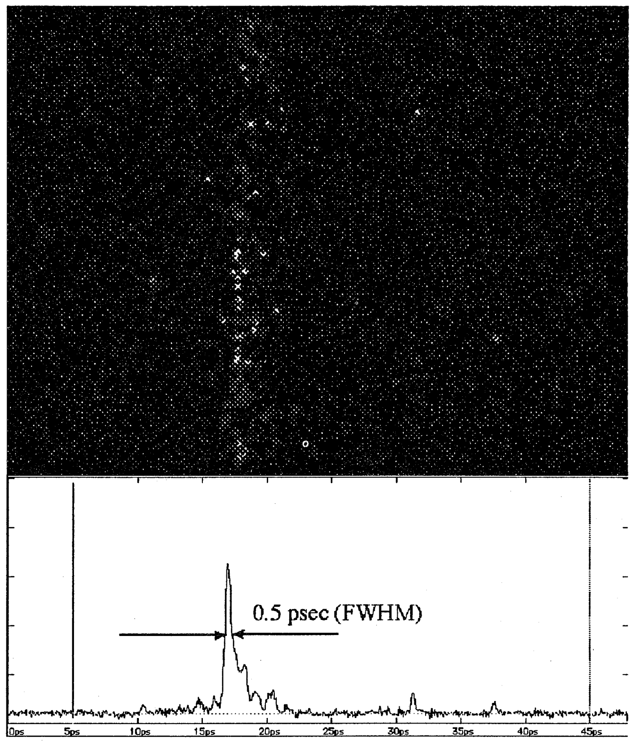

Fig.3 Streak image.

From Fig. 4, it is clearly to observe the efficiency of the velocity bunching effect. Each point indicates the average of 30 streak-image shots and the errors corresponds to the root mean square of them. Here, the error is mainly caused by the fluctuation of RF-timing. The minimum bunch width of 0.5 ps for the beam of 1 nC/bunch was achieved at the injection phase just after the zero-cross. While the average one is 1.3 ps.

Beyond the zero-phase, the electron bunch tends to increasing in width - because at that time the bunch will start to slip ahead and being decompression.

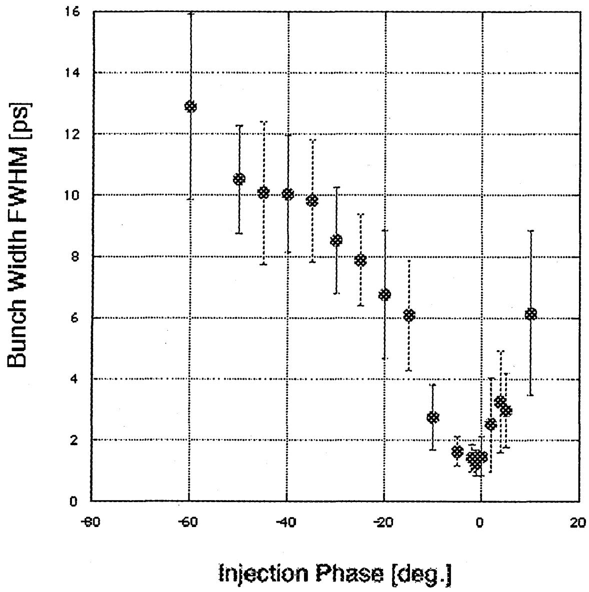

Fig. 4 The bunch width as a function of injected phase.

5. CONCLUSION

From the above results we see that the velocity bunching is a very useful compression method. The bunch width of 0.5 ps for the beam of 1nC/bunch can be obtained. Based on the rectilinear compression the effect is very sensitive with the injection, special at the phase near zero-cross. So that by changing the injection phase with smaller steps the shorter bunch width could be observed. Our experiment is somehow difficult to change the injection phase at every 1^0 due to the fluctuation of the changing injection phase device.

REFERENCES

[1] L. Serafini and M. Ferrario, "Velocity Bunching in Photo-injectors", Proc. of ICFA Workshop on the Physics of, and Science with, the Free-Electron Laser, Arcidosso, Italy, Sept. 2000, p. 87.

[2] M. Uesaka, *et al.*, Rad. Phys. Chem. **60**(2001)303.

[3] Y. Muroya, *et al.*, Nucl. Instrum. & Meth. A, **489**(2002)554.

[4] M. Boscolo, et al., Proc. of EPAC, Paris, 2002.