Generation of Femtosecond Electron Single Pulse at the S-band Linac

Kenichi KINOSHITA, Mitsuru UESAKA, Takahiro WATANABE, Toru UEDA, Koji YOSHII, Hideki HARANO, Fumio SAKAI*, Hideyuki KOTAKI*, Kazuhisa NAKAJIMA**, Hiroshi NAKANISHI**, Atsushi OGATA
Nuclear Engineering Research Laboratory
2-22 Shirakata-shirane,Tokai-mura,Naka-gun,Ibaraki 319-11,Japan
Japan Atomic Energy Research Institute
2-4 Shirakata-shirane,Tokai-mura,Ibaraki 319-11,Japan
*High Energy Accelerator Organization
1-1 Oho,Tsukuba,Ibaraki,Japan 305

1 Introduction

At the LINAC in Nuclear Engineering Research Laboratory Linac(NERL LINAC), femtosecond quantum phenomena researches are promoted at present, and the generation of the femtosecond single electron pulse is one of the inportant subjects there. Though the 700fs(FWHM) electron single pulse using the achromatic arc-type magnetic pulse has achieved in NERL LINAC, the shorter pulse for several applications is expected. In NERL LINAC the laser wakefield acceleration experiment and backward Thomson scattering X-ray generation experiment have been carried out in cooperation with High Energy Accelerator Organizaion(KEK) and Japan Atomic Energy Research Institution(JAERI). Here, the 200fs(FWHM) electron pulse is required. Energy-phase relation of the electron beam must be controlled precisely and the energy dispersion on the identical phase must be decreased in order to establish precise magnetic pulse compression. In NERL LINAC the thermionic electron gun has been used for an electron source. A laser photocathode RF electron gun, however, can produce smaller emittance electron beam, and it is more advantageous for the magnetic pulse compression.

2 Modified 18L Linac system

Femtosecond electron pulse generator using the chicane-type magnetic pulse compressor is composed of the laser photocathode RF electron gun, the accelerating tube and the chicane type magnetic pulse compressor(Chicane). The configuration of the 18L Linac is shown in fig. 1.

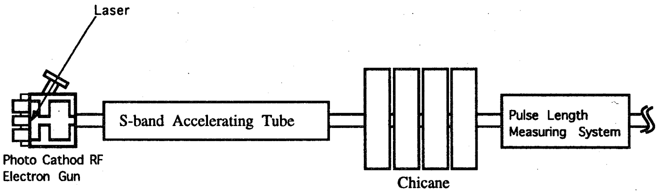

Fig. 1 : Schematic configuration of the modified 18L linac updraft section

2.1 Laser photocathode RF electron gun

In the laser photocathode RF electron gun, photoelectrons that rise from the cathode surface by injection of the YLF laser are accelerated by the RF of the resonance cavity. The frequency of the RF is 2856MHz. The pulse length of the electron pulse which rises in this electron gun is several picoseconds, and the energy is about 4.6MeV.

2.2 Constant gradient travelling-wave-type accelerating tube

constant gradient travelling-wave-type S-band accelerating tube whose frequency is 2856MHz is used for the accelerating tube. The electromagnetic-field distribution in the accelerating tube was calculated with the electromagnetic field analysis code SUPERFISH, and it was used for the electron orbit calculation by PARMELA. Though two accelerating tubes for the acceleration and for energy modulation are basically necessary for the magnetic pulse compression, there is only one accelerator. However, the method that the accelerating tube is used for acceleration and energy modulation simultaneously is examined considering the fact the laser photo cathod RF electron gun can produce electrons that have almost relativistic energy.

2.3 Chicane-type magnetic pulse compressor

The chicane consists of four rectangular bending magnets. In the chicane, a larger energy electron takes a shorter path. Therefore, the pulse compression is possible by giving the energy distribution in which a lower energy electron is put in the front part of a bunch. When the z -axis is taken in the propagating direction of the beam and the energy distribution of electrons in a bunch is written using coordinate $\zeta = \frac{2\pi}{\lambda}(z_0 - z)$ (λ is the RF wavelength) as $E(\zeta) = C_0 + C_1\zeta + C_2\zeta^2$, the position of an electron after the chicane, written by ζ', becomes,

$$\zeta' = \left(1 + b_1\frac{C_1}{C_0}\right)\zeta + \left(b_1\frac{C_2}{C_0} + b_2\frac{C_1^2}{C_0^2}\right)\zeta^2. \quad (1)$$

where b_1 and b_2 is the coefficients that are determined by shape and configuration of the chicane like,

$$b_1 = 4R_0 \arcsin\left(\frac{D}{R_0}\right) - \frac{4R_0D}{\sqrt{R_0^2 - D^2}} - \frac{2R_0D^2L}{(R_0^2 - D^2)^{3/2}}, \quad (2)$$

$$b_2 = \frac{4R_0D^2}{(R_0^2 - D^2)^{3/2}} + \frac{3R_0D^4L}{(R_0^2 - D^2)^{5/2}} + \frac{3R_0D^2L}{(R_0^2 - D^2)^{3/2}}. \quad (3)$$

R_0, D,and L are an the radius of curvature of the electron of nominal energy, the width of the magnet, and the gap between the magnets (shown in Fig. 2). The magnetic field is given so that the first order coefficient of ζ in eq. (1) becomes zero in the magnetic pulse compression. Thus, the pulse length after the compression depends on the secondary term, when the first order coefficient of ζ is made to be zero in equation (??zeta-p)). The value of the secondary term varies when the gap L of the magnets in the chicane changes. The relationship between L and the value of the secondary term for the electron pulse accelerated by 18L linac is shown in Fig. 3. It can be seen that the pulse can be shortened when L is extended. In the design L was determined so as to obtain the shortest pulse by the calculation of PARMELA.

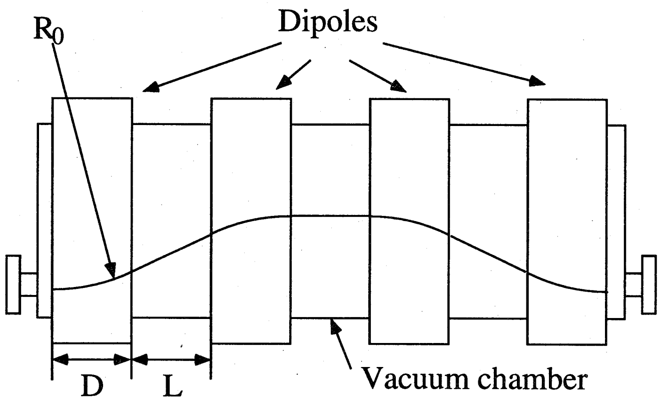

Fig. 2 : Chicane

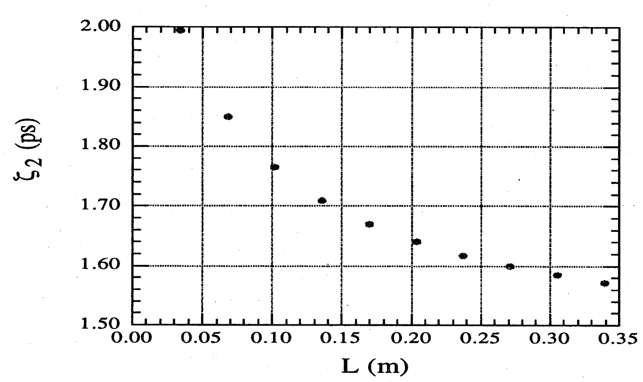

Fig. 3 : Magnet interval and pulse length

3 PARMELA simulation

The electron orbit calculation code PARMELA was used for the calculation. The pulse length of the laser in the electron gun was assumed to be 5ps(FWHM), the acceleration electric field amplitude of the electron gun be 100MV/m, and the electric field amplitude of the accelerating tube be about 8.5MV/m. Figure 4 is the longitudinal phase-space electron distribution at the exit of the photocathode RF electron gun. Here, the electric charge of the electron pulse is assumed to be 1nC. The pulse length is about 10ps and energy is about 5.2MeV in Fig. 4, and this pulse is sufficiently short and have sufficiently high energy for the acceleration in the accelerating tube. The normalized rms tranverse emittance of the electron pulse is about 2π mm·mrad, and it is far lower than that of our thermionic electron gun, which is about 100πmm·mrad. Figure 5 is the electron distribution and pulse shape at the exit of the accelerating tube. Electrons of lower and higher energy are put in the front and rear parts, respectively so that the pulse is compressible by the chicane. Figure 6 is the results at the exit of the chicane. The pulse length is compressed to about 200fs(FWHM).

4 Conclusion

The numerical analysis for the generation of the femtosecond electron pulse in the system that consists of the laser photocathode RF electron gun and the S-band linac was carried out using the electron orbit calculation code PARMELA, and the chicane type magnetic pulse compressor was designed. By the simulation it was confirmed that the electron pulse with the pulse length of 200fs(FWHM) can be generated in that system.

References

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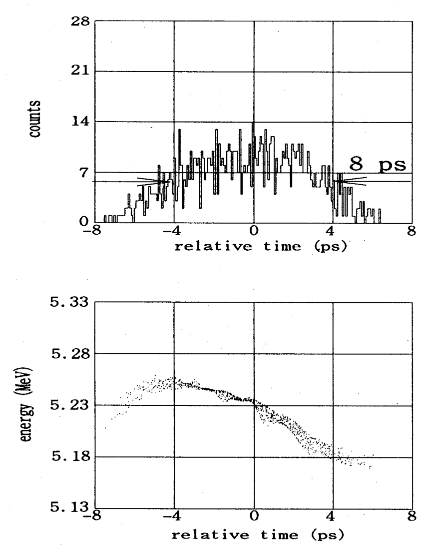

Fig. 4 : The electron distribution in the logitudinal phase-space at the exit of the electron gun

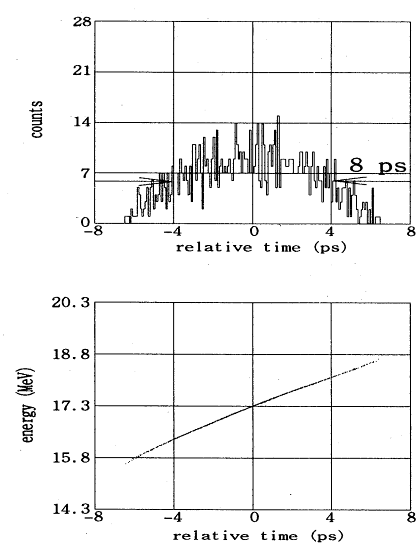

Fig. 5 : The electron distribution in the logitudinal phase-space at the exit of the accelerating tube

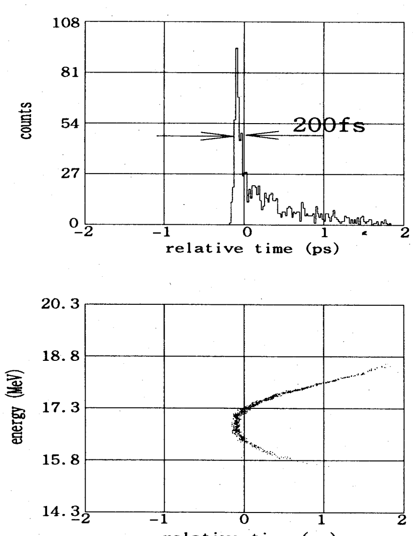

Fig. 6 : The electron distribution in the logitudinal phase-space at the exit of the chicane