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# Numerical Investigation of the X-band Femtosecond Linac Using a Laser Photocathode RF Electron Gun

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## Abstract

As the next stage of the existing subpicosecond electron linac, the femtosecond ultrafast quantum phenomena research project is proposed at Nuclear Engineering Research Laboratory (NERL) of Univ. of Tokyo. In this study, the feasibility of an X-band linac with a laser photocathode RF gun is numerically investigated for the femtosecond linac which is planned to be installed in the project.

## 1 Introduction

The construction plan of "Femtosecond Ultrafast Quantum Phenomena Research Facility" is progressing at NERL of Univ. of Tokyo as the next plan of the existing subpicosecond S-band (2.856 GHz) electron linac , which aims at elucidation and application of the beam-material interaction in the femtosecond time domain. The X-band (11.424 GHz) linac has been scheduled to be introduced in the project. The X-band RF wavelength is 1/4 shorter than the S-band, which can realize the compactification of the system and the excellent bunching effect can be expected due to the large gradient of the acceleration electric field. The optimum design on the system with a 150 kV thermionic gun and double subharmonic bunchers (SHB) as an injector has been carried out using electron orbit calculation code PARMELA, and the generation of the electron single pulse of 100 fs(FWHM) and 10 kA has been confirmed[1].

In the laser wake field acceleration experiment which is carried out as the cooperative research with KEK and JAERI, a laser photocathode S-band RF gun has been installed as an injector of the S-band 18L linac. It has been numerically evaluated to produce the electron single pulse of 200 fs(FWHM) and 1 nC[2]. Since the RF gun is triggered by the laser pulse, it has the intrinsic advantage to reduce the time jitter between an electron pumping pulse and a laser probing pulse and to establish precise synchronization between a linac and a laser in radiation physics and chemistry experiments. In addition, the RF gun has unique features so that it produces high quality electron beam with low emittance.So the feasibility of the X-band linac system with the laser photocathode RF gun is numerically investigated for the femtosecond linac in this study.

## 2 Basic System Configuration

Figure.1 shows the basic system configuration of the X-band linac proposed in this study. It consists of the laser photocathode S-band RF gun, the two X-band accelerating tubes and a magnetic electron bunch compressor. The solenoid magnetic field is applied properly for the transverse beam size suppression.

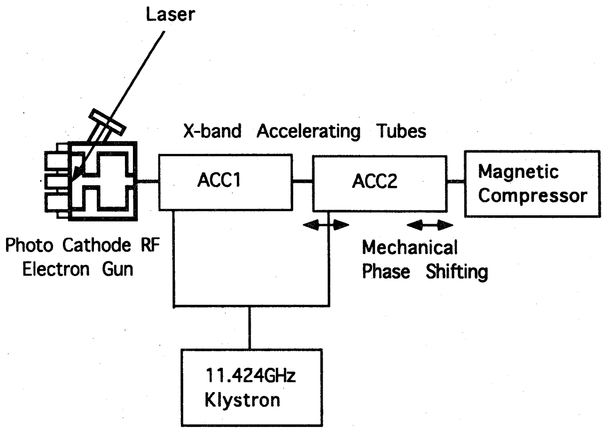
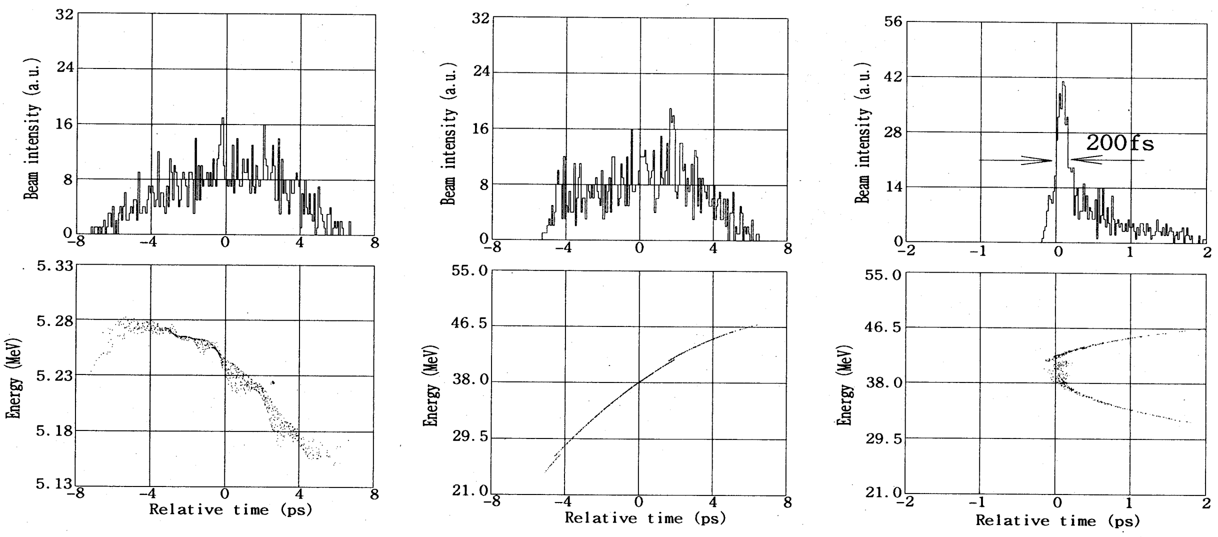


Fig.1 Schematic drawing of the X-band linac system.



(a) At the exit of the injector section.

(b) At the exit of the second accelerating tube.

(c) At the exit of the chicane.

Fig.2 Electron bunch structures in the longitudinal phase space.

The RF gun has a solenoid magnetic field for leading to the parallel beam while suppressing the emittance growth. Here, the range($z \leq 60$cm) in which the field exists is defined as an injector section. The same calculation parameters as ref.[2] are used for this section. The periodic inner structure of the X-band accelerating tube is the same as the second tube in ref.[1], which is designed to operate the 11.424 GHz constant impedance, travelling wave and $2/3\ \pi$ mode. Each tube is composed of 78 cells. The second tube is for the energy modulation of the electron bunch for the magnetic pulse compression and its phase is adjusted by the mechanical phase shifter. The RF power is supplied by the X-band klystron. 30 MW is supplied to the first tube and 10 MW to the second. The chicane type is used for the magnetic electron bunch compressor. The dimension is fixed equal to ref.[2], and only the magnetic field strength is adjusted to the energy distribution of the electron bunch.

## 3 Results

Figure.2(a) shows the the electron pulse right after the injector section, calculated by PARMELA. The electric charge of the electron pulse is assumed to be 1 nC. The pulse width is 14 ps(tail-to-tail) which is far shorter than the X-band RF's one period of 87.5 ps. Therefore, the single bunch pulse generation is possible without SHB, which makes the system simple as shown in Fig.1. This electron bunch has an extremely small transverse emittance of about 1.9 $\pi$ mm · mrad in normalized rms which is advantageous for the magnetic pulse compression.

The beam diameter just after the injector section is 13.4 mm(tail-to-tail) and larger than the $\phi$8.4 mm aperture of the X-band tube. Therefore, the transverse beam size was suppressed by the solenoid magnetic field as shown in Fig.3. The rms normalized transverse emittance $\varepsilon_{x,rms}$ and the beam size $x_{max}$ defined as $\sqrt{\beta\varepsilon_{x,rms}}$ are also plotted in Fig.3 where $\beta$ is the beta fuction. The electron beam becomes parallel with the smaller diameter after overfocused, which indicates that this field has the similar effect to the combination of two magnetic lenses. Figure.3 also indicates that the emittance increase near the focus due to the space charge is less than 1.5 times. The emittance grows inside the accelerating tube due to the RF-produced lateral force especially for the low energy electron far from the axis. Therefore the first tube is placed so that its entrance is near the focus.

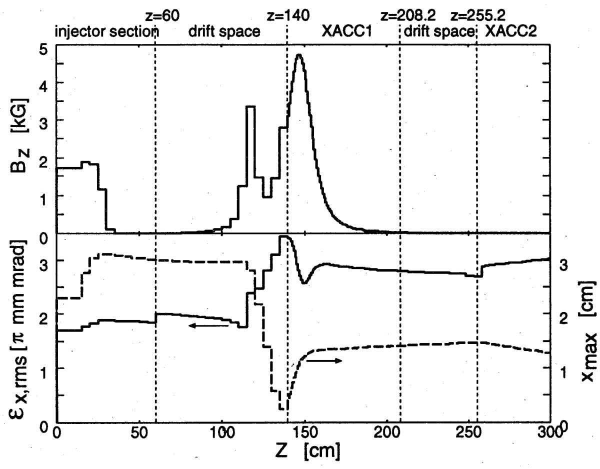


Fig.3 Distribution of the Solenoid magnetic field $B_z$ and evolutions of the rms normalized transverse emittance $\varepsilon_{x,\mathrm{rms}}$ and beam size $x_{\mathrm{max}}$.

For carrying out the pulse compression by the chicane, the energy modulation is necessary so that a rear electron in the bunch has a higher energy, and it is desirable that the energy distribution is rectilinear[2]. The electron energy must be around 30 MeV from the viewpoint of electron beam applications. The phase of the accelerating tube was adjusted to satisfy these requirements as well as possible. The electron pulse at the exit of the second tube is shown in Fig.2(b). The electrons are accelerated to about 37.5 MeV. The pulse width is slightly compressed since the electrons are accelerated on the stable phase in the first tube.

The electron pulse at the chicane exit is shown in Fig.2(c). The pulse width is compressed to about 200 fs(FWHM). The initial 1 nC electrons all penetrate. The emittance is about 3.5 $\pi$ mm · mrad, less than twice of the initial value. The maximum magnetic field strength of the chicane is 1.24kG.

## 4 Conclusion

By the combination of the laser photocathode S-band RF gun, the X-band accelerating tubes and the chicane type pulse compressor, it was confirmed numerically that the electron single bunch pulse can be generated with the pulse width of 200 fs, the peak current of 2 kA and the ultra low emittance. The condition of the injector section was fixed in this study, however, the system is expected to be more optimized by adjusting this section to match to the X-band accelerating tube. For example, the system will be compacted if the solenoid magnets attached with the RF gun is modified in order to generate the parallel beam with a proper size to the tube aperture. If the pulse width at the injector exit is shotened by some contrivance such as shortening the laser pulse width, the linearity of the electron energy distribution is improved at the magnetic compressor's entrance, which will cause the pulse compression efficiency higher.

## References

[1] A.Takeshita et al., "Optimization of design of the 100 fs 10 kA X-band linac", Proc. of the 21th Linear Accelerator Meeting (1996) pp.299-301.

[2] K.Kinoshita et al., "Improvement of NERL S-band linac aiming at femtosecondl electron pulse", Proc. of the 22th Linear Accelerator Meeting (1997).