GENERATION OF FEMTOSECOND ELECTRON SINGLE PULSE USING LASER PHOTOCATHODE RF GUN

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Abstract

A new laser photocathode RF electron gun was installed in the second linac of the S-band twin linac system of Nuclear Engineering Research Laboratory(NERL) of University of Tokyo in August in 1997. Since then, the behavior of the new gun has benn tested and the characteristic parameters have been evaluated. At the exit of the gun, the energy is 4.7 MeV, the charge per bunch 1 nC, the pulse width is 10 ps(FWHM), respectively, for 6 MW RF power supply from a klystron. The electron bunch is accelerated up to 17 MeV The horizontal normalized emittance is 1 π mm.mrad. Then, the bunch is compressed to be 440 fs(FWHM) with 0.35 nC by the chicane-type magnetic pulse compressor. The gun is planned to be used for femtosecond X-ray generation via the head-on Thomson scattering and laser wakefield acceleration in 1998.

1 INTRODUCTION

A laser photocathode RF electron gun is one of the most attractive electron sourceS since it can supply the relativistic electron bunch of high quality both transversely and longitudinally. Namely, low transverse and longitudinal emittances are advantageous for the brightness of synchrotron radiation and bunch compression, respectively. Especially, those features are evitable for X-ray free electron laser such as SASE[1]. Several works have been done for its development aiming the application to FEL and linear collider[2,3,4,5]. We installed a new S-band laser photocathode RF electron gun in the second S-band twin linac system[6] in August in 1997. The gun was constructed by KEK, Brookhaven National Laboratory(BNL) and Sumitomo Heavy Industries based on much experiences at BNL[7]. The purpose is to apply it to the joint research project on laser wakefield acceleration among KEK , NERL of University of Tokyo and JAERI Kansai-establishment[8,9]. The first subject here is to produce femtosecond low emittance electron bunch and to check the quality of the gun. As the next steps, we plan to perform femtosecond X-ray generation via the head-on Thomson scattering and laser wakefield acceleration. Technical feasibility and reliability of the gun are totally checked considering the scope of the applications. Updated results are presented in this paper.

2 BEHAVIER OF LASER PHOTOCATHODE RF GUN

Upgraded second S-band linac in the twin linac system with the new laser photocathode RF gun is depicted in Fig.1. We also constructed the chicane-type magnetic pulse compressor. Two 6 MW S-band klystrons feed the RF power to the RF gun and tube individually.

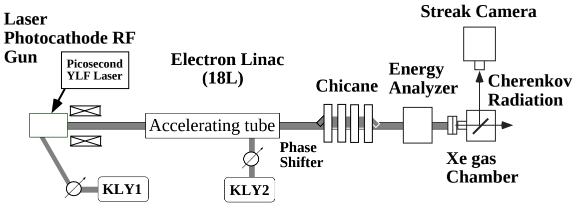


Figure:1 Upgraded second S-band linac in the twin linac system.

The 150 kV thermionic electron gun, subharmonic buncher and two prebunchers were replaced with the RF gun so that the injector section became very simple.

The cavity of the gun has S-band 1.6 cells. 10 ps (FWHM) light pulse with 100 μJ energy is produced by the fourth hanomics(264 nm) of the YLF laser(1.06 μm) and irradiates the copper cathode at 40 dgree angle at 10-50 Hz. Since the basic mechanism of electron emission is photoelectronic, the lifetime of the copper cathode is intrinstically unlimited. The work function of copper is 4.6 eV(270nm). The quantum efficiency around the work function is 5.8×10^{-5}. 6 MW RF power is fed to the cavity to induce 100 MV/m maximum field gradient. The time-duration of the fed RF is 4-8 μs. The peak energy at the exit of the gun is 4.7 MeV. The solenoid magnet is attached to the cavity for transverse emittance compensation against space charge effect. The emittance was measured by the conventional way with focusing magnets, a phosper screen and CCD camera. Measured nomalized horizontal and vertcal emittances as a function of the RF phase at laser injection in the gun are shown in Fig.3.

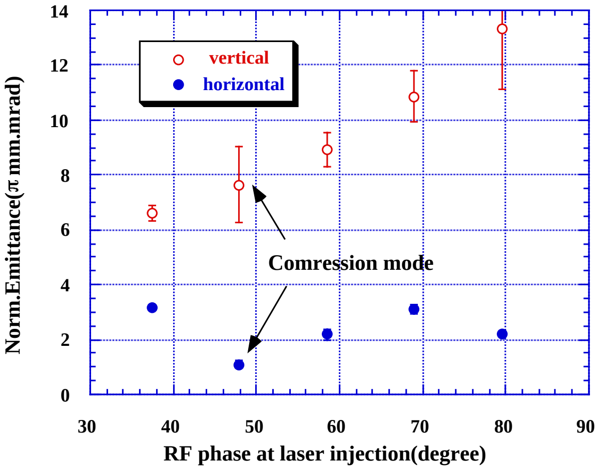
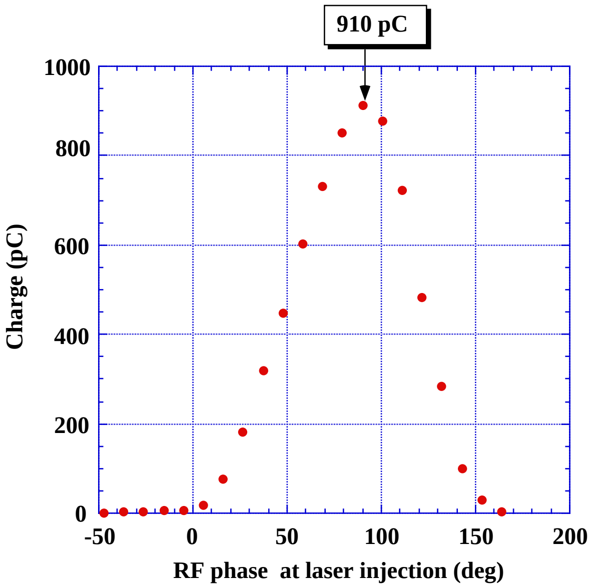


Figure:2 Measured emittances as a function of the RF phase at laser injection in the cavity.

Lowest horizontal emittance of 1 π mm.mrad in normalized rms is achieved. The reason of larger vertical emittance is the elliplic laser spot at the cathode surface due to the 40 dgree oblique injection and the rotaion of electrons in the cavity due to the solenoidal magnetic fields. We plan to tune the spot shape to be round later. The beam spot is ϕ3 mm. The charge per bunch was measured at the exit of the gun as shown in Fig.3.



Figire:3 Measured charge per bunch as a function of the RF phase.

Maximum charge per bunch is 0.91 nC. Then, the low emittance electron beam is accelerated up to 17 MeV and simultaneously its energy profile is modurated for the magnetic pulse compression in the accelerating tube where the maximum field gradient is 8.5 MV/m.

We are always making efforts to reduce dark current by the baking of the cavity and the RF aging and observing its behavior. It is very important to reduce the dark current because it would be rather harmful for the applications such as FEL from several aspects of noise. The dark current is multi-bunched existing in every traveling accelerating RF phase. Therefore, each peak currrent is negligible while the total charge during the whole RF pulse is more than photoelectrons. So far, its charge per 4 µs RF pulse is 2 nC at 50 Hz. When the RF pulse is elongated to 8 µs, it increase to 26 nC. We are going to continue the efforts.

3 BUNCH COMPRESSION FOR FEMTOSECOND SINGLE BUNCH

The chicane-type magnetic pulse compression was designed by using PARMELA. It consists of four identical bending magnets. In order to compensate the nonlinearity of the energy modulaion in the accelaring tube, we optimized the longitudinal length of the magnet and the gap between the magnets. The numerical results of the pulse shape after compression obtained by PARMELA is shown in Fig.4.

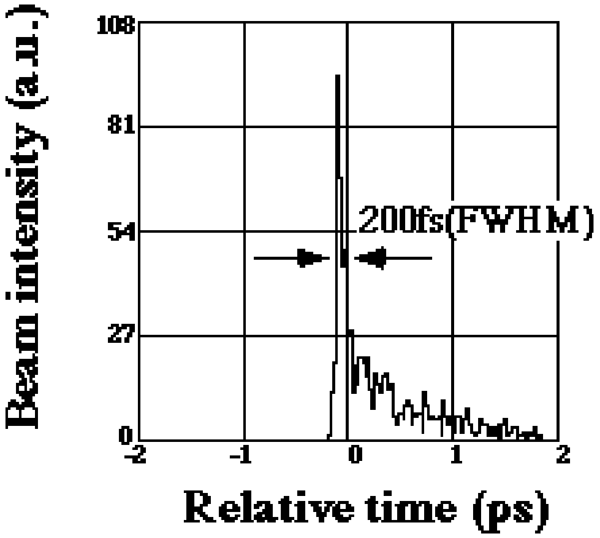


Figure:4 Numerical results of compressed elctron bunch by PARMELA.

The pulse width is 200 fs at FWHM although the pulse has a long tail downward. The pulse shapes of the bunches with and wthout compression were measured by a single shot by the femtosecond streak camara (FESCA-200, HAMAMATSU PHOTONICS), which time-resolution is 200 fs, via Cherenkov radiation emitted in a Xe-gas chamber attacthed at the end of the linac(see

Fig.1). Measured streak image and pulse shape of the bunches are shown in Fig.5.

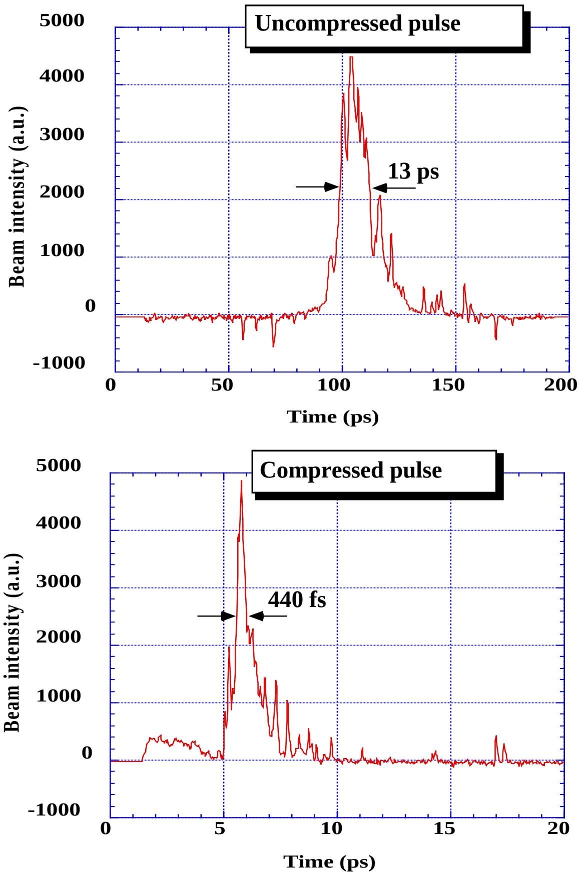


Figure:5 Measured pulse shapes with and without comprssion.

It is observed that 13 ps bunch is compressed to 440 fs(FWHM). The average charge of the compressed bunches is 0.35 nC. This reduction of charge is mainly due unoptimized optics and alignment of the linac, which should be improved. The streak measurement was done shot by shot. Due to the time-jitter between the emission at the gun and the RF phase, the pulse shape and width varies shot by shot. The average pulse width is 800 fs. We carried out the calibtration of the time-resolution of the camera using a 100 fs Ti:Sapphire laser after the beam experiment. We found out that the error at FWHM of the camera at that time is 370 fs assuming the Gaussian error function and the law of error propagation. When we subtract the error from 440 fs, it become 245 fs at FWHM, which agrees well with the numerical result. Again here the advantage and effectiveness of the low emittance beam from the laser photocathode RF gun was confirmed.

There is another discussion about the precision of the space charge force of PARMELA as for such a ultrashort bunch. Actually the noninertial space charge force and the coherent radiation force[10,11] in a bending magnet are not considered in PARMELA. Recently a preliminary numerical simulation of our bunch compression in the chicane was carried out and the effect of the above forces on the pulse length was calculated to be negligible[12]. On the other hand, we are investigating the possibility to get experimental evidence of the emittance growth due to the effect in the chicane.

4 CONCLUSION

The new laser photocathode RF electron gun and the chicane-type magnetic pulse compressor were installed in the second S-band linac in the twin linac system. The details of their characteristics were measured and evaluated. The lowest emittance is 1 π mm.mrad in normalized rms with 4.7 MeV and 1 nC. After acceleration up to 17 MeV, 13 ps bunch was compressed to 440 fs(FWHM) with 0.35 nC. The femtosecond electron single bunch of the low emittance is going to be used for the femtosecond X-ray generation via the head-on Thomson scattering and the laser wakefield acceleration in 1998. Both advantages and drawbacks of the gun continue to be checked including the technical feasiblity and reliability for such appilcations. We hope that our data would be informative to future users of the laser photocathode RF electron gun.

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