FEMTOSECOND ELECTRON BEAM GENERATION BY THE S-BAND LASER PHOTOCATHODE RF GUN AND LINAC

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Abstract

A 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 been tested and the characteristic parameters have been evaluated. At the exit of the gun, the energy is 3.5 MeV, the charge per bunch 1-2 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 horizontal and verticel normalized emittances of 3π mm.mrad were achieved simultaneously. Then, the bunch is compressed to be 440 fs(FWHM) with 0.35 nC by the chicane-type magnetic pulse compressor . The linac with the gun and a new femto- and picosecond laser system is planned to be used for femtosecond pulseradiolysis for radiation chemistry in 1999.

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 a 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 and femtosecond X-ray generation via Thomson scattering among Nuclear Engineering Research Laboratory of University of Tokyo, High Energy Accelerator Research Organization(KEK) , and Japan Atomic Energy Research Institute [8,9], the picosecond pulseradiolysis for radiation chemistry and the picosecond time-resolved X-ray diffraction. The main subject here is to produce a femtosecond low emittance electron bunch and to enhance the quality and stabliy of the gun. Technical feasibility and reliability of the gun are totally accomplished considering the scope of the applications. Updated results are presented in this paper.

2 PERFORMANCE OF LASER PHOTO-CATHODE RF GUN

Upgraded twin S-band linac linac system with the 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.

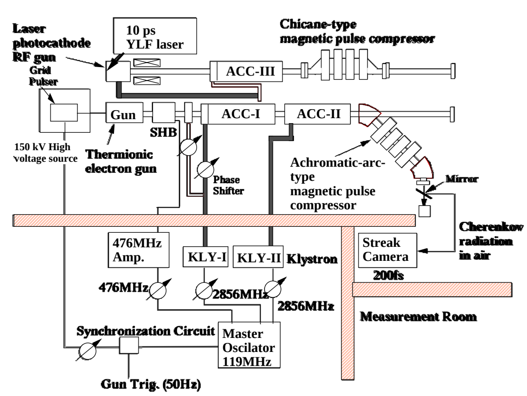

Figure:1 Upgraded second S-band linac in the twin linac system.

The 90 kV thermionic electron gun, subharmonic buncher and two prebunchers were replaced with the RF gun so that the injector section becomes very simple.

The cavity of the gun has S-band 1.6 cells. 10 ps (FWHM) light pulse is produced by the fourth harmonics (263 nm) of the YLF laser(1.05 μm) and irradiates the copper cathode at 40 degree angle at 10-50 Hz. Since the basic mechanism of electron emission is photoelectric, the lifetime of the copper cathode is intrinsically unlimited. The work function of copper is 4.6 eV (270nm). The quantum efficiency around the work function is $1x10^{-4}$. 6 MW RF power is fed to the cavity to induce the field gradient close to 100 MV/m. The time-duration of the fed RF is 4-8 us. The peak energy at the exit of the gun is 3.5 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 phosphor screen and CCD camera. Horizontal and vertical emittances are uniformly 3 π mm.mrad in normalized rms. Here we controled transwerse laser spot to be circular at the cathode ever for oblique injection by making original spot be elliptic so that the laser spot became circular at the cathode. If we do not perform the above treatment, the emittance becomes not uniform and the lowest horizontal emittance of 1 π mm.mrad is achieved while the vertical one is 7 π mm.mrad. The beam spot is ϕ3 mm. The charge per bunch is 2nc at maximum. Maximum charge per bunch is 2 nC for 75 μJ laser energy at the cathode. Then, the low emittance electron beam is accelerated up to 17 MeV and simultaneously its energy profile is modulated for the magnetic pulse compression in the accelerating tube where the maximum field gradient is 8.5 MV/m.

We are 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 current 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 modulation in the accelerating tube, we optimized the longitudinal length of the magnet and the gap between the magnets. Calculated pulse width is 200 fs at FWHM. The pulse shapes of the bunches with and without compression were measured by a single shot by the femtosecond streak camera (FESCA-200, HAMAMATSU PHOTONICS), which time-resolution is 200 fs, via Cherenkov radiation emitted in a Xe-gas chamber attached at the end of the linac. Measured streak image and pulse shape of the bunches are shown in Fig.2.

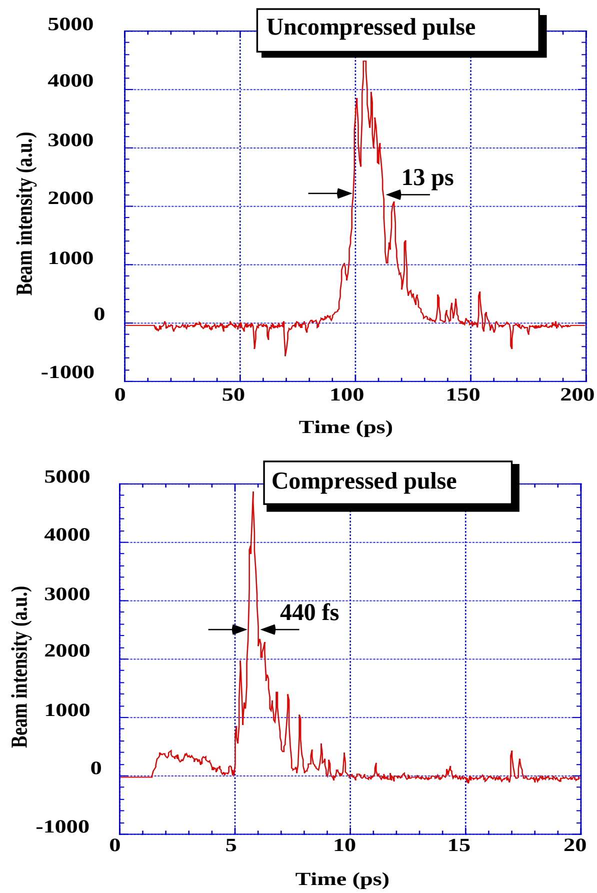

Figure:2 Measured pulse shapes with and without compression.

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. We carried out the calibration 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 238 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 are several discussions 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]. We are going to perform the measurement of the emittance growth due to the effect in the chicane in 1998.

4 SYNCHRONIZATION BETWEEN LASER AND ELECTRON

We are investigating the pecision of synchronization between the laser and electron pulses. We measured it by the femtosecond streak camera. About 100 data of streak measurements were accumulated and the time interval between the two pulses was evaluated. Its histogram is given in Fig.3. If we assume the distribution to be Gaussian, the standard deviation is 3.5 ps. This linac has been applied to the laser wakefield acceleration and the femtosecond X-ray generation via the head-on Thomson scattering[13]. Further, a new femto- and picosecond laser system is going to be installed for femtosecond pulseradiolysis for radiation chemistry in 1999.

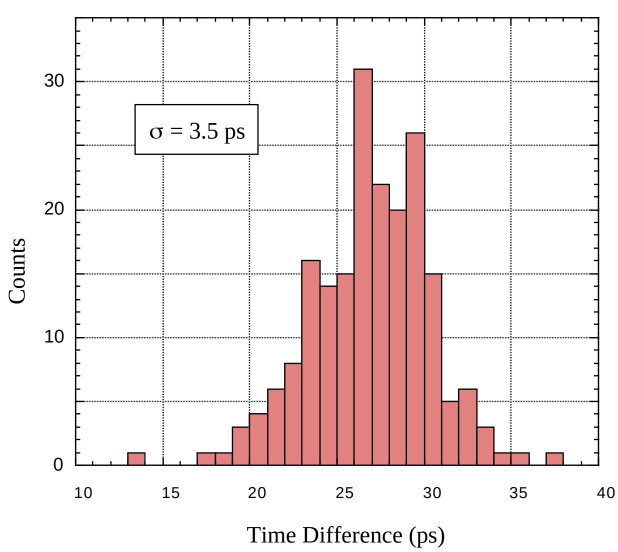

Figure:3 Histogram of time interval between laser and electron pulses.

5 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. Horizautelly and vertically uniform emittance is 3 π mm.mrad in normalized rms with 3.5 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 has been used for. Both advantages and drawbacks of the gun continue to be checked including the technical feasibility and reliability for such applications. The linac with new gun has been devicated to the laser wakefield acceleration and the femtosecond X-ray generation via the head-on Thomson scattering so far and to femtosecond pulseradiolysis for radiation chemistry in near future.

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