PROTOTYPE EXPERIMENT PREPARATION OF A 54.167MHz LASER WIRE SYSTEM FOR FEL-THz FACILITY AT CAEP*

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Abstract

In this paper, a prototype experiment preparation of a 54.167 MHz laser wire system is presented, which will be used to measure the beam size of a CW DC gun built as an electron source of FEL-THz facility in China Academmy of Engineering Physics (CAEP). The rms beam size is less than 1 mm and the average current of the electron beam is more than 1 mA. This new-type LW system ultilizes the excess power other the photocathode drive laser and becomes much cheaper and simpler. Plus, it can distinguish beams with different energies which are very close in ERLs. The system layout and the simulation results are also presented.

INTRODUCTION

In the future high average power free electron lasers (HAP FELs) and energy recovery linacs (ERLs), electron beams have a high repetition rate from MHz to GHz and an MW-grade power, which will destroy any target arranged for measurements [1–3]. As a result, the determination of basic electron beam properties including transverse profile, emittance and bunch length should be noninvasive. One advanced method for noninvasive beam size and emittance diagnostic is the laser wire (LW) scanner [4–10], which is based on laser-electron Compton scattering.

There are two major LW methods: one is to intercept electron beams with continuous wave (CW) laser in an optical cavity for storage rings [8,9] and the other with a high power single laser pulse for linacs [6,10]. However, neither of them is optimal for the diagnostics of electron beams with MHz repetition rate in HAP FELs or ERLs. The single pulse LW requires a special care of the optical components to endure high energy density laser pulse and thus it is obviously expensive. The scan speed is limited by the laser repetition rate and the impact on the beam is rather stronger. The CW LW needs complicated optical cavity technologies and most of the laser power will be lost in the intervals between electron bunches. Plus, neither of them can measure the bunch length because of the jitter among RF field, electron beams and laser field. Furthermore, they can not distinguish beams with different energies which are very close in ERLs.

In order to avoid the disadvantages mentioned above, Murokh [11] and Evtushenko [12] proposed a high repetition LW for BNL ERL and JLab's HAP FEL, respectively. This new-type LW improves the scattered photon yield by improving the repetition frequency, and becomes faster and more-efficient. The only drawback is that it needs a new mode-locked laser system fitting to the electron beams, which makes it relatively expensive and its jitter unpredictable.

In this paper, an improved high repetition LW system, which utilizes the excess power of the photocathode drive laser, is presented and analyzed, and its design study in China Academy of Engineering Physics (CAEP) is introduced. This improved one can be much cheaper, faster, naturally mode-locked and may be suitable for beam longitudinal diagnostics because the average effect cancels the jitter.

EXPERIMENT SETUP

Layout of the CAEP high repetition LW facility is shown in Figure 1.This system is going to be installed on the CAEP FEL-THz facility [13]. A 54.167MHz drive laser system generates short pulse with 532nm wavelength for electron production. A JLab type photocathode high-voltage DC gun is used to generate 200∼350 keV, high quality electron bunches [14]. The photocathode material is GaAs, of which the quantum efficiency (QE) would be 0.5∼10%. To generate 1mA CW electron beam, 23 mW∼0.47 W laser power is needed.

The average output power of the drive laser is 8 W. The excess laser power can be used to build a laser wire scanner to measure the electron beams. The laser is separated into two parts: one reaches the cathode surface, the other passes through the laser delay and scan systems, and collides with the electron beam in the interaction cavities. The photoelectric multiplier tubes (PMTs) are used to count the scattered photons. The photons before the accelerator are collected by a detective cavity, while the ones after the accelerator are separated from electron beam by a dipole magnet. The counting rate of scattered photons is:

$$R_{sc} = f \cdot (N_{sc}), \tag{1}$$

where N_{sc} is the photon yield in each Thomson scattering and f is the colliding frequency, which is exactly equal to the laser and electron repetition.

This naturally mode-locked system reduces complexity and takes advantage of the extra laser power, thus making itself much cheaper and simpler. The megahertz repetition can improve the scanning speed and reduce the jitter because of the average effect. In the ERLs, electron beams

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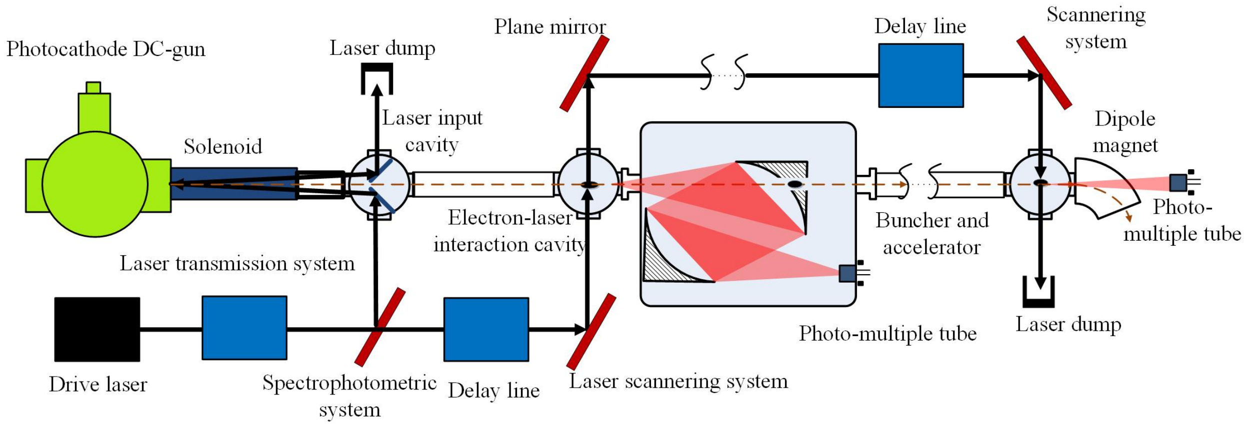

Figure 1: Layout of the improved CAEP high repetition LW facility (not to scale).

with different energies are arranged in very small intervals (as shown in Fig. 2), so only this mode-locked laser probe can measure them separately. Furthermore, N_{sc} is very small, which means that the impact on the electron beam can be ignored.

The optimized electron pulses qualities, laser qualities and main machine parameters are listed in Table 1. We use the code PARMELA [15] to simulate the dynamics of electrons subject to static electric field, RF field, magnetic field, and their self-field. Some of the optimization simulations can be found in reference [16], while others are under publication.

Table 1: The CAEP LW Facility Parameters

Parameters	**Value**
Physical dimension	
From gun cathode to interaction point one	90.6 cm
From gun cathode to interaction point two	450 cm
Electron pulse at interaction point one	
Bunch radius/(Guassian, rms)	1 mm
Bunch length/(Guassian, rms)	8 ps
Bunch charge	90 pC
Bunch kinetic energy	200∼350 keV
Electron pulse at interaction point two	
Bunch radius/(Guassian, rms)	1 mm
Bunch length/(Guassian, rms)	3 ps
Bunch charge	90 pC
Bunch kinetic energy	6∼8 MeV
Laser at interaction point one and two	
Average power	3 W
Transverse radius/(Guassian, rms)	25 μm
Longitudinal size/(Guassian, rms)	6.4 ps
Repetition	54.167 MHz

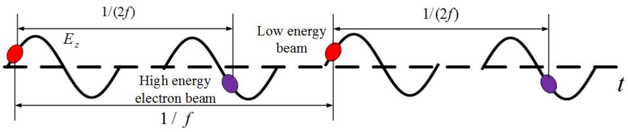

Figure 2: Diagrammatic sketch of different energies electron beams' interval in ERLs.

SIMULATION RESULTS

The Numerical results of this improved LW system are shown in Table 2, where E_k is the electron kinetic energy and λ_{sc} is the wavelength of scattered photon. In the calculation, the formula in reference [17] are used. The counting rate of the scattered photon is enough for single photon counting (SPC) system, which works in the kilo-Hertz range, indicating that a single measurement can be finished in 1 minute.

Table 2: Numerical Calculation Results

Position (cm)	E_k **(MeV)**	$(\lambda_{sc})_{min}$ **(nm)**	$(R_{sc})_{max}$ **(s^{-1})**
90.6	0.2	162.1	5495
90.6	0.35	103.8	5993
450	6	1.64	6675
450	8	0.96	6679

We use the Monte Carlo code CAIN [18] to simulate the LW process. The results are shown in Figure 4 and 3, where N_c means the number of macro-particle counting. Some numerical curves are also posted.

From Figure 3, one can see that the acceptance angle of scattered photon is reduced obviously when E_k is increased from 200 keV to 8 MeV. The Monte Carlo computation error is greater when the macro-particle number is less, so the counting of scattered photon decreases faster than the numerical calculation.

The basic proof of LW working is shown in Figure 4, where the photon yields of different energy electron beams have different maximum in order to be distinguished clearly. The guassian fitting shows that the detected rms radius in y direction would be 1.03 mm when $E_k = 200$ keV and 0.994 mm when $E_k = 8$ MeV, respectively. The results agree well with the actual value .

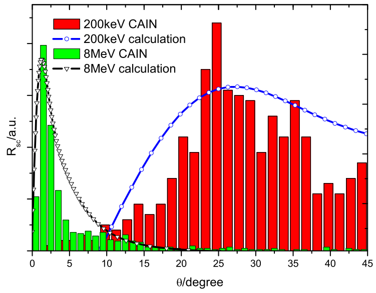

Figure 3: The normalized scattered photon number compared with electron density distribution in y direction.

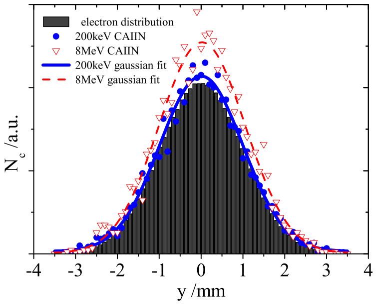

Figure 4: The normalized scattered photon number compared with electron density distribution in y direction.

EXPERIMENT PREPARATION

The high repetition picosecond laser system is now under commissioning. The power system, the photo-cathode DC-gun and the GaAs cathode are ready for experiment. The vacuum leak detection of scattered photon detective cavity has been finished, as shown in Figure 5. The beamline components installation and alignments are to start soon. The laser transport line and scanning system have been constructed. We foresee an improved laser wire prototype experiment this year. The super-conducting accelerator is going to be installed next year. Then the second LW experiment will be arranged.

CONCLUSIONS

In this paper, we have introduced an improved laser wire system which is much cheaper and simple by utilizing the drive laser to measure the electron beam size, and have presented a design of such a facility at CAEP, including the system layout, numerical calculation and Monte Carlo simulation. The calculation and simulation indicate that the measurement resolutions will be less than 100 μm and the scanning time better than 1 minute. The experiment preparation is in progress. This improved LW system will be a compact and powerful tool for high repetition high average power FELs and ERLs.

Figure 5: The scattered photon detective cavity construction.

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