GENERATION OF FEMTOSECOND ELECTRON PULSES

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Abstract

At the Fast Neutron Research Facility (FNRF), Chiang Mai University (Thailand), the SURIYA project has been established aiming to produce femtosecond electron pulses utilizing a combination of an S-band thermionic rf-gun and a magnetic bunch compressor (α-magnet). A specially designed rf-gun has been constructed to obtain optimum beam characteristics for the best bunch compression. Simulation results show that bunch lengths as short as about 50 fs rms can be expected at the experimental station. The electron bunch lengths will be determined using autocorrelation of coherent transition radiation (TR) through a Michelson interferometer. The paper discusses beam dynamics studies, design, fabrication and cold tests of the rf-gun as well as presents the project current status and forth-coming experiments.

INTRODUCTION

Femtosecond electron and photon pulses have become interesting tools for basic and applied applications, especially in time-resolved experiments [1,2,3]. Such short electron pulses can be used to generate intense coherent far-infrared (FIR) radiation, ultrashort X-ray pulses, and free electron laser (FEL). Although, photocathode rf-gun is a promising source to generate a high brightness ultra short electron pulses [4], it involves a complex laser injector and requires high financial cost. On the contrary, a thermionic cathode rf-gun with suitable compression system can play similar role to produce intense electron beam with pulses duration in order of femtosecond [5].

At SURIYA, femtosecond electron bunches will be produced from a combination of an S-band rf-gun with thermionic cathode and a magnetic bunch compressor in the form of an α-magnet [6]. The schematic layout of SURIYA beamline is presented in Fig. 1.

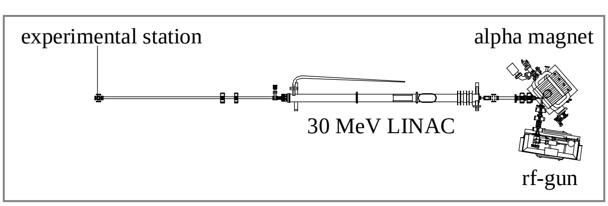

Figure 1: Schematic layout of SURIYA set up at FNRF.

The rf-gun generates 2-3 MeV electron beams, which are then traveling through the α-magnet for bunch compression. A 30 MeV linac is used to achieve higher energy as well as more confine beams. At experimental stations, coherent FIR radiation will be generated as coherent TR either for beam diagnostics or other experimental uses.

RF-GUN AND RF SIMULATIONS

Fig. 2 is illustrated the SURIYA rf-gun cross section and 3D-view showing the thermionic cathode attached at the end wall of the half-cell (HC) and electron beam exits out at the end of the full-cell (FC). The field in the two cells is coupled through an external coupling cavity.

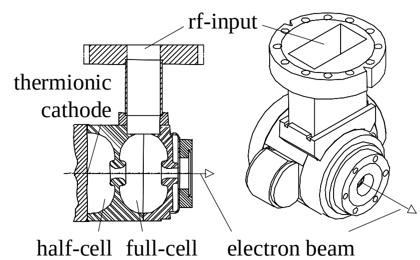

Figure 2: Rf-gun cross-section and 3D-view.

Numerical simulations for rf characteristics of the SURIYA rf-gun were performed using the EM field solver code SUPERFISH [7]. Based on 2D-simulation, SUPERFISH cannot be used to investigate 3D-shape include coupling cavity, rf-input and vacuum pumping ports. This leads to a deviation of the simulated results from the measured values. SUPERFISH results, however, give fair ideas regarding to the rf-gun electrical properties as well as the helpful scaling law concerning the rf-gun dimension and its resonant frequency (f_{rf}). During fabrication processes, modifications of the rf-gun dimension based on SUPERFISH scaling law were performed together with the rf-measurements.

BEAM DYNAMICS STUDY

A particle-in-cell computer code PARMELA was used to simulate and investigate particle dynamics through the EM fields inside the rf-cavities [8]. In the studies the 6-mm diameter thermionic cathode is set to emit a 2.9 A uniform distribution electron beam which is represented by 100,000 macroparticles per 2856 MHz rf-period with space-charge effects.

Longitudinal Particle Dynamics

Due to a sinusoidal time-varying field inside the cavities a very concentration of particles are accumulated

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in the head (defining as the field becomes acceleration) of the bunch leading to a small correlated particle distribution between energy and time as shown in Fig. 3. Ten percent of high-energy particles concentrate at the head of the bunch appears in the length of some 10-20 ps.

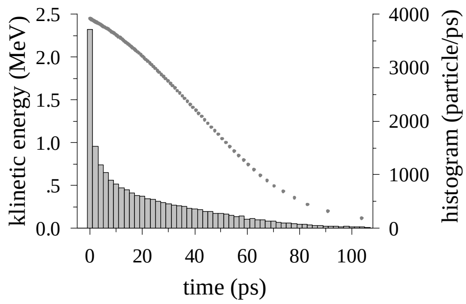

Figure 3: particle distribution in energy-time phase space for a single S-band electron bunch at the rf-gun exit.

The concave shape of the particle distribution at the rf-gun exit in Fig. 3 matches well to bunch compression in the α-magnet. It will rotate clockwise as the beam travels through the α-magnet with α loop paths of the length (S) depending on the particle momentum (cp) and the magnetic gradient (g) as $S \approx [cp/g]^{1/2}$. Thus, lower momentum particles follow shorter path than the higher one, leading to simply magnetic bunch compression. The value of the α-magnet field gradient is chosen to compensate velocity dispersion so that the shortest bunches are generated at the desired experimental station.

A computer code Bcompress is used to simulate particles dynamics from the gun exit to the experimental station. Locations of the experimental station where the shortest bunch length can be achieved as well as other parameters can be determined using the code. Among those, the choice of the electric accelerating field employed in each cell of the rf-gun highly affects the bunch compression. The simulation results suggested that the field ratio between HC and FC should be 1:2 for optimum bunch compression [9]. The temporal particle distribution after compression and acceleration with respect to the initial momentum at the rf-gun exit is presented in Fig. 4. The expected bunch length, including transverse path length dispersion, at an optimum experimental location is 53 fs rms with a total charge of 94 pCb.

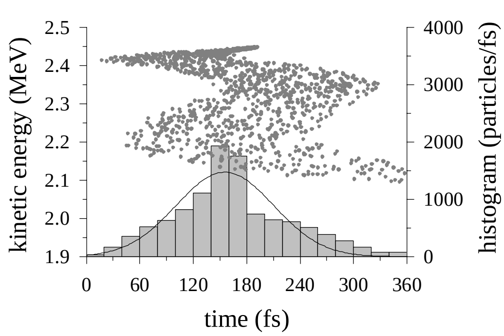

Figure 4: Particle distribution in energy-time phase space after bunch compression and transport to the experimental station.

Transverse Particle Dynamics

Since bunch lengthening depends quadratically on beam divergence, reducing the beam divergence facilitates ultrashort bunch generation. For this reason, the SURIYA rf-gun was therefore designed with a flat cathode plate and optimised the iris radii to reduce the radial rf-field effects. PARMELA calculation including the finite effect of the thermal cathode emittance was performed to simulate the transverse beam dynamics. The simulation results reveal that a normalized emittance of 3.8 mm-mrad can be achieved at the rf-gun exit [9]. Some of the beam parameters from PARMELA and Bcompress simulations are listed in Table 1.

Table 1: Some parameters for the optimised rf-gun.

Parameters	**Value**
Max. beam momentum, cp (MeV)	2.91
Avg./max. field in half-cell (MV/m)	23.9/29.9
Avg./max. field in full-cell (MV/m)	45.5/67.6
Cathode emission current (A)	2.9
Charge/bunch (pCb)	94
Peak current (A)	707
Bunch length, rms (fs)	52.8
$\varepsilon_{n,rms}$ at rf-gun exit (mm-mrad)	3.8

FABRICATION AND COLD TESTS

The HC and the FC of the rf-gun have been fabricated precisely, based on the SUPERFISH results, out of OFE copper cylindrical blocks, at the Thai-German Institute (Thailand). The cavities were first machined to resonate at a slightly different frequency from the target frequency (2856 MHz) to leave some rooms for fine modification. Preliminary cold tests of the rf-gun cavities before brazing have been preformed using Network Analyser at the Stanford Synchrotron Research Laboratory (SSRL/ SLAC), USA, and at the National Synchrotron Research Centre (NSRC), Thailand. Cold test results of the rf-cavities ready for brazing show that the f_{rf} of the rf-gun is very close to 2856 MHz at the operating temperature of 45^o. The rf-gun was then brazed at the National Synchrotron Radiation Centre (SSRC), Taiwan, in an O_2-free high temperature furnace.

The rf-cold tests of the rf-gun were performed again after brazing at SSRL to measure the f_{rf} of individual rf-cells and determine the coupling between the two cells by adjusting the tuning rod of the coupling cavity while measuring longitudinal field profile. The measurement is done by Bead-Pull technique, which is performed by introducing a 2.36 mm diameter dielectric sphere bead at each position in the rf-gun. This results in a resonant frequency shift that reflects directly the longitudinal electric field magnitude at that location. Fig. 5 illustrates the consistency between normalized axial longitudinal fields from SUPERFISH and the bead-pull measurement. The ratio of the maximum field amplitude in the FC to the HC from SUPERFISH calculation and Bead-Pull measurement is 2.186 and 2.067, respectively.

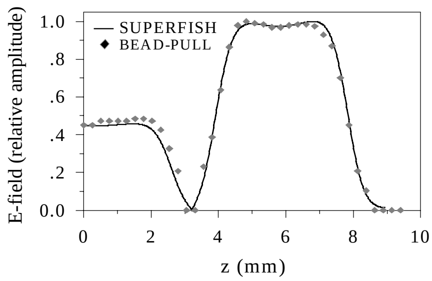

Figure 5: Longitudinal electric field distribution on axial axis from SUPERFISH and Bead-Pull measurement.

The coupled-cell resonant frequency and Q-factor were measured at the Rajamangala Institute of Technology (RIT), Thailand. Table 2 shows a comparison of the predicted rf-parameters obtained from SUPERFISH to those measured values in the rf-cold tests.

Table 2: Rf-parameters of the rf-gun calculated using SUPERFISH comparing to the cold test results.

Parameter		SUPERFISH	Cold Tests
f_{rf}	HC/FC	2881/2862	2855/2858
	Coupled-cell	2862	2855
Q factor	HC/ FC	15334/12980	-
	Coupled-cell	13037	12979

PRESENT STATUS OF SURIYA

The optimised rf-gun, the α-magnet and the 30 MeV SLAC type linac including 5 MW S-band klystrons for the rf-gun and the linac as well as the beam transport line have been installed and the system is now being commissioned The picture of SURIYA system is illustrated in Fig. 6.

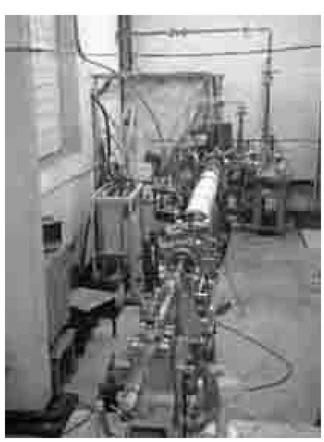

Figure 6: Beamline set up at SURIYA project.

At an experimental station, coherent TR radiated at wavelength longer than the bunch length will be generated by introducing the Al-foil at 45° with respect to the electron path. The backward TR emitted at 90° can be used for bunch length measurements or FIR spectroscopy. For the electron bunch as short as we expected, the bunch length measurement by autocorrelation of coherent TR should be done in vacuum to avoid pulse spacing in the ambient air [10]. An in-vacuum Michelson interferometer as shown in Fig. 7 is ready to be installed for the measurement.

Figure 7: In-vacuum Michelson interferometer set up.

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