BEAM CHARACTERIZATIONS AT FEMTOSECOND ELECTRON BEAM FACILITY

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Abstract

The SURIYA project at the Fast Neutron Research Facility (FNRF) has been established and is being commissioning to generate femtosecond (fs) electron bunches. Theses short bunches are produced by a system consisting of an S-band thermionic cathode RF-gun, an alpha magnet (α-magnet) serving as a magnetic bunch compressor, and a SLAC-type linear accelerator (linac). The characteristics of its major components and the beam characterizations as well as the preliminary experimental results will be presented and discussed in this paper.

INTRODUCTION

The femtosecond electron facility was established and developed since 2000 at FNRF under SURIYA project [1] to study fs electron and photon pulses generation and applications. Femtosecond electron bunches generated from SURIYA set-up can be used for direct applications such as electron diffraction [2], or to produce either far-infrared (FIR) radiation or femtosecond X-ray pulses [3, 4]. The SURIYA project set-up is located at the basement of the FNRF building for radiation shielding reason. The basic components of SURIYA are a thermionic RF-gun, an α-magnet, a SLAC-type linear accelerator (linac), beam steering and focusing elements, beam diagnostic instruments, RF system, and control units. Figure 1 shows a schematic layout of SURIYA set-up and area.

Presently, commissioning and characterizations at SURIYA are underway. Preliminary beam characterizations reveal that up to 900 mA electron beams of 2.4 MeV can be produced from the RF-gun. Optimization for beam acceleration and beam guidance during post acceleration is currently in progress. The beam energy after acceleration is expected to be about 20-25 MeV. At experimental stations, FIR radiation will be produced in form of coherent transition radiation (TR) while fs X-ray pulses will be produced as Parametric X-ray (PXR). Electron bunch lengths will be measured by autocorrelation of the coherent TR via a FIR spectroscopy in a Michelson interferometer. More details regarding to the radiation productions are presented in reference [5].

GENERATION OF FEMTOSECOND ELECTRON BUNCHES

The SURIYA electron source and compression system, consists of a thermionic RF-gun and an α-magnet serving as a magnetic bunch compressor, of which the schematic layout is shown in Fig. 2. The RF-gun is 1-1/2 S-band standing wave cavities. It has a dispenser thermionic cathode with 6-mm diameter attached at the flat wall of the first half-cell. The cathode is heated by an AC power supply to produce an electron beam with thermal energy. Electrons are accelerated or decelerated depending on the phase of the supplied RF-oscillating fields. The RF-gun structure was designed to accelerate electrons such that the first electron gains maximum energy and get through the half-cell before the RF-fields become decelerating phase. The later ones feel less acceleration and therefore gain less energies. This results in energy-time distribution in which higher energy electrons locates at the head of the bunch followed by the lower energy electrons.

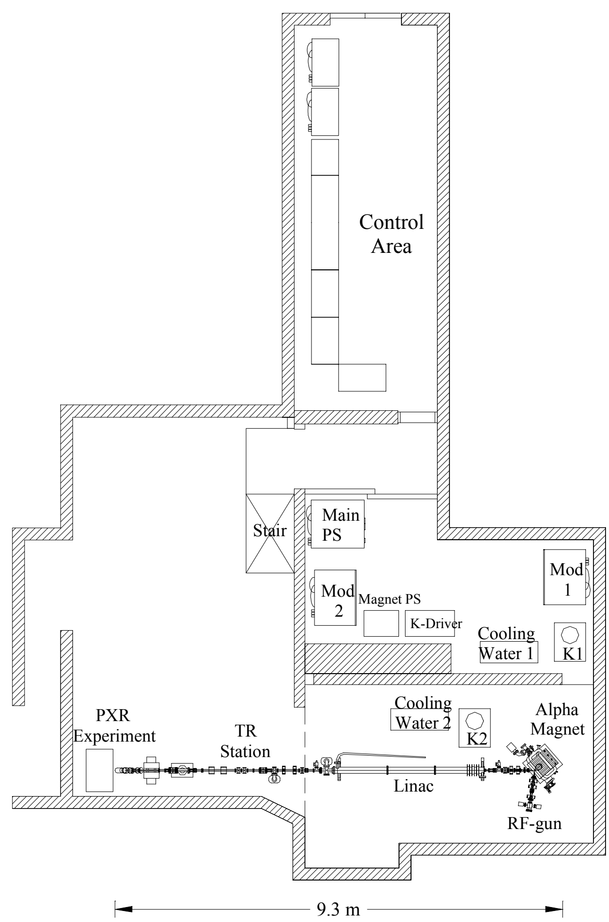

Figure 1: Schematic layout of SURIYA project at the Fast Neutron Research Facility (FNRF).

Bunch compression takes place in the α-magnet where higher energy electrons transverse longer closed path than

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the lower ones. This method provides a simple yet effective electron bunch compression. Since the ultrashort bunch generation is the most concern for our applications, the RF-gun design and optimization of electron bunch compression have been studied to serve this purpose [6]. Inside a vacuum chamber of the α-magnet, two slits were installed as an energy filter. These energy slits is very helpful in the improvement of beam transmission through the linac without a big loss since we can select electrons with small energy spread. Results from measurements and testing of the RF-gun and α-magnet performance are listed in Table 1.

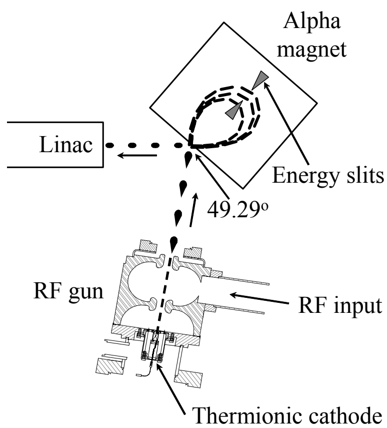

Figure 2: Schematic diagram of electron source and compression system.

Table 1: RF-gun and α-magnet Performance

Parameters	**Value**
f_{rf} of RF-gun from cold tests (GHz)	2.855
Q-factor of RF-gun from cold tests	12979
Average field ratio of HC:FC (bead-pull)	2.186
Max. beam energy from RF-gun (MeV)	2.4
α-magnet current (A)	265
α-magnet gradient (G/cm)	450

POST ACCELERATION AND BEAM TRANSPORT SYSTEM

Post Acceleration and RF System

To obtain higher beam energy and radiation collimation, the electron beam is further accelerated in a SLAC-type linac to reach about 20-25 MeV. The RF-gun and linac are powered by separately 5-MW klystrons with their associated modulators. At low RF-power, an RF oscillator tank generates 2.856 GHz signals. The RF signal is split into two parts by a 90° Hybrid directional coupler. One signal feeds the gun RF-amplifier and the other goes to the linac RF-amplifier via an adjustable phase shifter. The klystron can produce about 5 MW peak power with a maximum pulse width of 6 μs at 5-20 Hz repetition rates. The high power RF signals from klystron enter into waveguide section through a ceramic RF window and then are transmitted to the RF-gun and the linac through a rectangular waveguide system pressurized with SF6 to prevent electrical discharges. RF-power is measured using directional couplers installed at the waveguide section for the RF-gun and the linac. At the end of the waveguides, there are ceramics windows to separate the SF6 pressurized waveguides from the rest of the beam transport line.

Beam Transport System

To minimize the transverse dimension of electron beam, some beam focusing and steering elements are needed. There are several quadrupole and steering magnets placing along the beam transport line. The air-coil small dipoles are used as beam steering elements. The quadrupoles magnets are used mainly for beam focusing and can also be used for beam emittance measurement. The beam emittance measurement will be performed by quadrupole scan technique.

Combination of a 0.4 Tesla electromagnetic dipole magnet and a Faraday cup are placed at the end of the beam transport line serving as an energy spectrometer and a charge collector. The spectrometer had been designed and simulated by using the computer code RADIA [7]. The field distribution measurement was performed to verify the simulation results and to be used for beam energy measurement.

BEAM CHARACTERIZATIONS

In this section some of preliminary beam diagnostics at SURIYA, especially the beam characteristics from the RF-gun will be presented and discussed. At the initial stage of beam commissioning, we fed 3.5 MW RF-power pulses of 5-6 μs long to the RF-gun. Electron peak currents of about 1A with sharp rising edge were observed. There are evidences indicating significant the cathode self-heating from back-bombardment. To reduce the effect of the electron back-bombardment due to high average RF-power, we reduce the RF-pulses to 3-5 μs for the RF-gun operation. This results in lower beam currents, shorter current pulses with slower rise times. Measured signals of incident and reflected RF-power as well as the beam current signals are illustrated in Fig. 3. The pulse length of the incident RF signal is 4 μs (FWHM) with about 4 MW peak power.

Beam Current and Charge

Beam current of the electron macropulse is measured by a current monitor that installed at several locations along the beam transport line. The current monitor is a pulse transformer with a ferromagnetic core. The winding coil around the core works as the secondary while electron beam acts as a primary coil. The electron beam pulse signals from the RF-gun and after the α-magnet are shown in Fig. 3. The RF-gun produces electron macropulses with the pulse length of about 1.5 μs and 100 ms apart at a repetition rate of 10 Hz. Each macropulse consists of about 4000 electron microbunches which are spaced at 350 ps. About half of the electrons can get through the α-magnet before guiding to further acceleration in the linac.

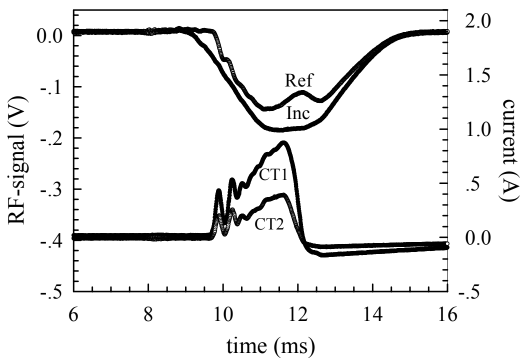

Figure 3: Measured waveforms for the incident RF-power (Inc) and the reflected RF-power (Ref) at the RF-gun, the current monitor after the gun exit (CT1), and after α-magnet (CT2).

The amount of electrons generated from the RF-gun depends significantly on the cathode temperature. The study of cathode temperature effects on electron density to determine the range of cathode temperature was performed and the results are presented in Fig. 4 for three different RF-power levels. The results reveal that the cathode has to be heated to reach temperature threshold where electrons can be emitted. At a temperature lower than the limit no electron will be emitted. On the contrary, heating to a temperature above the limit will lead in current saturation. The study results are also show that the higher RF-power employed to the RF-gun, the lower heating is needed to be supplied to the cathode. At the operation with the peak power of RF about 3.0-4.5 MW, the RF-gun can produce the electron beam with a pulse current of about 700-900 mA depending on the cathode temperature and the RF-power.

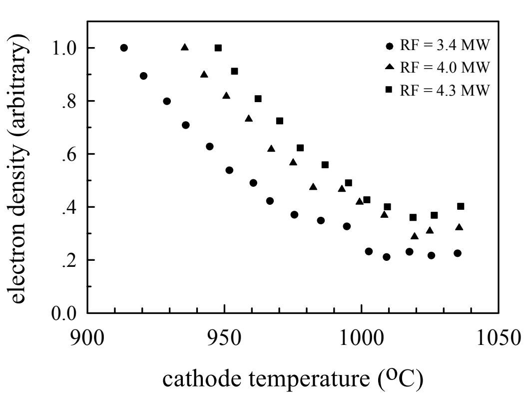

Figure 4: Electron density from the RF-gun as function of cathode temperature.

Beam Energy and Image

The electron beam energy is measured by using energy slits inside the α-magnet. Preliminary experimental results show that we can generate the electron beams with kinetic energy of about 2.4 MeV at the exit of the gun. Electron energy after acceleration by the linac measured via a small air-coil dipole magnet is about 15-17 MeV. Energy spectrometer is needed for more precise measurement results. We plan to measure the electron energy as a function of the linac temperature and phase of the RF-power.

The electron beam transfer line was commissioned to the end of the beam line in April 2005. The image of the first beam on the fluorescent screen at the end of the beamline is shown in Fig. 5.

Figure 5: Image of the first beam at the end of the beamline.

SUMMARY

The description of the accelerator set-up at the SURIYA project is presented as well as the status of the commissioning and beam tests. Preliminary measurement results show that the electrons beam of energy about 2.4 MeV with current of 700-900 mA can be generated from the RF-gun while the cathode is heated at temperature of 900-1040°C. More beam diagnostics are needed to characterize the beam properties after the linac acceleration as well as at the experimental station which planed to be station for FIR radiation and PXR.

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