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COMPTON X-RAY SOURCE

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Abstract

In an effort to develop a monochromatic, tunable source of X-rays in the 20-85 KeV energy range, a 5.5 cell X-band RF gun has been designed and tested. Together with a 1.05 m long high gradient accelerating structure (an NLC Collider component), this system can generate and accelerate a beam of electrons to energies in excess of 60 MeV. Monochromatic X-rays are generated, via the Compton Effect, through a nearly head-on collision with a multi-terawatt TW laser beam. We describe the experimental setup and report on recent measurements of electron beam parameters as well as measurement techniques.

INTRODUCTION

In collaboration with U.C.Davis, a program is underway at SLAC to develop a source for generating monoenergetic, tunable X-rays in the multi-KeV energy range (20-85 KeV). At completion, it will have demonstrated a proof-of –principle device useful in the diagnosis and treatment of cancer.

X-rays are generated via the Compton Effect by a (nearly) head-on collision of a multi-MeV electron beam with a 100 fs high power, infrared laser beam (1-2 TW). Since the requirement of monoenergetic X-rays depends critically on the electron beam energy-uniformity and quality, a laser driven RF gun is employed to generate sub-picosecond electron bunches. Further acceleration is accomplished through the use of a high gradient X-band accelerator structure developed for the Next Linear Collider (NLC).

Currently we are undergoing tests to determine and verify the performance of this device. Identifying useful diagnostics has also been a major component of the current program.

We have performed measurements of beam energy and energy resolution using a precision spectrometer. In addition we have used measurements of beam current to estimate the RF gun quantum efficiency. Dark current contributions to the total current have been measured. We will describe the status of beam size measurements. Details of the RF Gun design and initial emittance measurements have been previously described [1]. Electron-Laser timing issues will also be discussed.

MAIN BEAMLINE

The main beamline is shown in Figure 1. The electron beam is generated in an X-band, 5.5 cell RF gun and emittance-compensating Solenoid. The beam is generated by a UV laser beam reflecting into the beamline by UV-coated mirrors in the "Mirror Chamber". This chamber also contains an insertable Ce:YAG scintillator which permits the observation of the generated electron beam. A 1.05 m high gradient accelerator structure permits the further acceleration of the electron beam to energies in excess of 60 MeV. The accelerated beam can be viewed in the "Diagnostic Chamber" located immediately after the accelerator. A pair of diagnostics, remotely insertable into the beam, is used to view the beam and permit emittance measurements. A triplet of quadrupoles is then used to focus the beam to a narrow spot in the "Interaction Chamber". In this chamber the electron and laser beams collide nearly head-on. An additional chamber, the "observation chamber" is used to measure beam spot size using an Aluminum pellicle and a Ce: YAG scintillator as well as an aid in timing the colliding

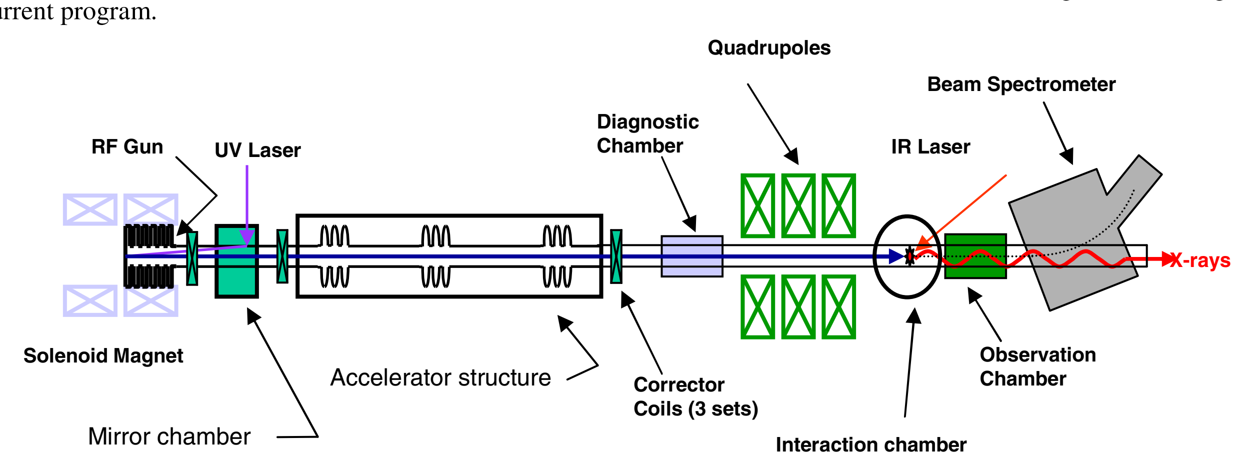

Figure 1. Schematic of Compton Beamline

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beams. A recessed window in one wall of this chamber permits observation of the beams to within 2 cm of the beam axis. The spectrometer at the end of the beamline serves several purposes. It bends the beam out of the beamline so that only X-rays leave along the beamline axis. The bent beam is also viewed and energy analyzed. A Faraday cup located behind a pair of energy analyzing slits is used to measure the beam current. The beamline exit port is fitted with a thin window (either Aluminum or Beryllium) to permit low energy X-rays to pass through virtually unattenuated.
There is also a Ce: YAG scintillator in the beamline path to view the electron beam when the Spectrometer is not operational.

SPECTROMETER- BEAM MEASUREMENTS

The spectrometer is designed to bend an electron beam 45 degrees into an isolated Faraday cup. Energy defining slits sample the beam energy with a ±0.5 % energy window. This device has proven very useful, not only in determining the beam energy, but also in adjusting accelerator RF phasing for minimum energy spread and peak energy. It also very clearly separates the beam from any dark current produced in the accelerator. Ce: YAG scintillators are mounted on the front surfaces of the slits which permit observation of the beam energy profile from a 45 degree viewport. See Figure 2.

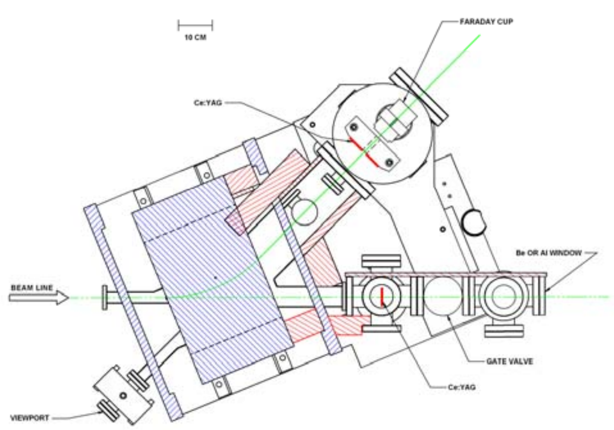

Figure 2. Schematic of Spectrometer

Figure 3 shows the results of performing a CCD screen capture of the beam on the low energy Ce:YAG Scintillator. The spectrometer is set so that the beam is bent slightly less than the slits. A Gaussian profile is fit to the measurements. The resultant energy rms width is 0.23% of the beam energy. The beam energy for this measurement was 53 MeV. Since the total beam can be made to pass through the Analyzing slits, a knife-edge measurement was also performed. In this measurement, performed at 54 MeV, The total beam was allowed to pass through the slits into the Faraday cup.

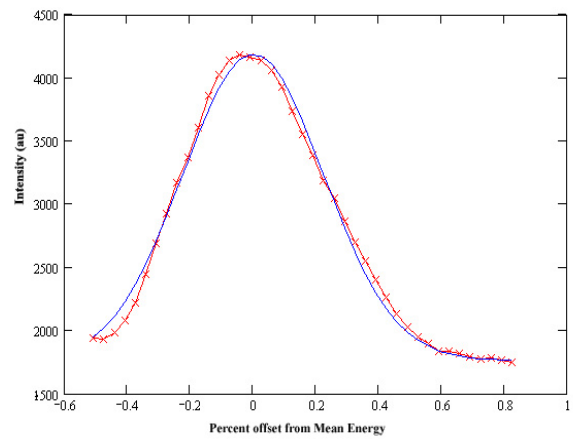

Figure 3. Measured beam Intensity profile and Gaussian fit.

The spectrometer field was then incrementally reduced and the reduction in beam current measured. These data points were fit with an error function profile, i.e.

$$F(x,r_i)=\frac{r_0}{2}\left[1+Erf\left(\frac{x-r_1}{\sqrt{2}r_2}\right)\right]+r_3$$

where the r's are the fitting parameters. The results are shown in Figure 4.

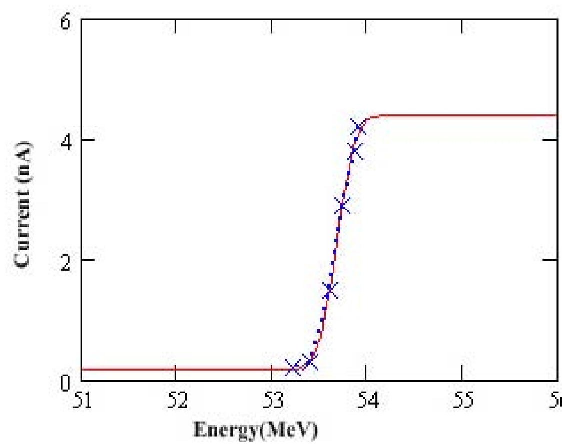

Figure 4. Results of "knife-edge" measurement and fit. (X-axis is Energy in MeV, y-axis is current in nA.)

The resulting rms width using this method is 0.28%.
The actual measured beam energies agree to approximately 5% of the values determined from RF simulations on the RF gun and accelerator design measurements. They are always lower. The highest beam energy generated thus far has been 55 MeV. This value has been chosen for convenience and is not a limitation on the setup. The accelerator has been RF

tested for many hours at accelerating gradients of 73 MV/meter and the spectrometer is designed for steering 200 MeV electron beams into the analyzing chamber. The RF gun is usually operated to deliver 6-7 MeV beams. It was designed to generate 7.3 MeV. This corresponds to a surface gradient of 200 MeV/m.

BEAM CURRENT /QUANTUM EFFICIENCY

The beam current has been measured both in an in-line Faraday cup at the end of the beam line (with the spectrometer off) and with the Faraday cup in the energy analyzing beam path. Since dark current is also present in the in-line Faraday cup, the UV laser light is blocked to measure its content. The results of these measurements are shown in Table 1.

Table 1. Comparison of In-line current with Analyzed Current

Total In-line Current (nA)	In-line Dark Current (nA)	Net Current (nA)	Analyzed Current (nA)
5.6	0.99	4.6	4.5
10.5	1.4	9.1	9.0

During these measurements there was essentially no dark current contribution in the energy-analyzed beam. With knowledge of the beam current and the UV laser energy, the quantum efficiency of the RF Gun copper cathode can be determined. From several measurements, the resulting quantum efficiency is $\approx 5.3*10^{-5}$ with an uncertainty of approximately 10% due to fluctuations both in beam current and laser energy.

BEAM SIZE

Measurements are still in progress to minimize the beam spot size at the interaction chamber. We use a triplet of quadrupoles positioned after the accelerator to accomplish the focusing. Currently we are measuring the spot size using the Optical Transition Radiation from an aluminum pellicle located in the observation chamber positioned at an angle of 45 ° to the beamline. Results from a scan of a CCD camera image are seen in Figure 5. The units along the x-axis are in pixels. In this measurement, there are 190 pixels/cm. The best Gaussian fit to the data (both shown in Figure 4, indicates a beam rms radius of 95 µm. This is somewhat larger than desired. We anticipate reducing this value by a factor of 2-3 in the near future.

TIMING ISSUES

In order to obtain collisions between the laser beam and electron beam, they must arrive at a precise location in space at the same instant of time. We establish the location in space by passing the beams through a narrow aperture in a tantalum mask positioned in the interaction chamber. We have 4 aperture sizes of 50-250 µm diameters available. Thus far we have passed both beams through the 100 µm aperture.

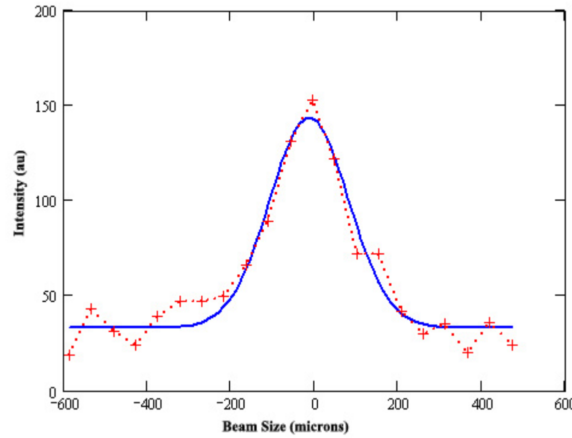

Figure5. Beam profile in vertical direction.

We are currently working on the problem of adjusting the timing between the electron beam and IR laser so that they arrive at the collision point at the same instant. This is accomplished by adjusting the laser path length using a set of mirrors mounted on a movable stage. The stage can be moved in micron increments. Currently we are estimating the timing between the electron beam and IR laser by measuring the UV light from the cathode on the pellicle in the observation chamber with the IR reflected from the Tantalum mask positioned at the interaction point. (We will shortly use optical transition radiation from the electron beam directly instead of the UV light.) We use a fast photomultiplier, having a rise time of 780 ps, and a 2.25 GHz, 8 GSa/s scope (Agilent model 54846B) for this measurement. A timing difference of less than 100 ps is observable but is still too coarse for our requirements.

We will shortly replace the photomultiplier with a fast (40ps rise time) photodiode. We are also preparing to install a streak camera at the Interaction Chamber to reduce the timing uncertainty to ≈ 1ps.

REFERENCES

1. A.E.Vlieks, G.Caryotakis, C. DeStefano, J.P.Heritage, E.Landahl, N.C.Luhmann, Jr., D. Martin, A.Menegat, *Initial Tests with an X-Band PhotoInjector at SLAC*, p 358, 6th Workshop on High Energy Density and High Power RF, 2003, AIP Conference Proc. 691