

ELECTRON TRANSPORT AND EMITTANCE DIAGNOSTICS IN CIRFEL

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Electron pulses for the Northrop Grumman Compact Free Electron Laser CIRFEL are produced at a repetition rate of up to 10 Hz by the illumination of a Mg photocathode with a photon injector 261 nm seed laser system mode locked to the 20th sub-harmonic of 2.856 GHz. Presently the system is being operated in the 10 to 12 MeV energy range and spontaneous radiation has been observed. We present some preliminary results on electron beam characterization including its energy spread, energy stability, and spontaneous radiation observations.

I. INTRODUCTION

The Compact IR Free Electron Laser facility CIRFEL, under construction by Northrop Grumman Corporation at the Princeton University's Physics Department under a Joint Research Agreement has entered the commissioning phase. When completed it will serve as a platform for advanced research in Physics and Engineering. The facility will be used initially by groups working in the area of biophysics and multi-photon dissociation for pollution control. The CIRFEL system is described, summarizing the progress made with some of the measurements evaluating the electron beam parameters.

II. CIRFEL SYSTEM

The CIRFEL system comprises of the following system components, (1) High brightness photocathode electron gun, (2) Photo-injector laser, (3) 30 MW S-Band RF source, (4) the beam transport system, (5) the FEL microwiggler, (6) the FEL optical cavity, and (7) associated support hardware sub-systems. CIRFEL which occupies two levels with the photo-injector and the high power RF system on one level, and the rest of the system on the ground floor has been previously described [1].

A. High Brightness Photo cathode Electron Gun

The high brightness photocathode gun designed for CIRFEL is an extremely bright source of electron beams and is specified by the parameters shown in Table 1. The Photoelectron source comprises of a 6 mm diameter Mg cathode illuminated by a photon injector and is situated in a 3.5 cell; Pi mode RF cavity, which produces a very high gradient (60 to 80 MeV/meter) on its surface. The

"electrodeless emission" of electrons is controlled by the laser and allows extremely smooth control of the spatial and temporal profiles, and the electron current. The CIRFEL system started with an electron beam bombarded LaB6 cathode, but it was replaced by a Mg cathode operating at room temperature. This has improved the system performance enormously.

Table 1
Electron Beam Specifications

| | |
|----------------------|----------------------------|
| Beam Energy | < 7 - 13 MeV |
| Total Charge | 1 - 2 nC |
| Pulse Width(FWHM) | 5 - 7 psec |
| Normalized Emittance | < 6 Π mm-mrad |
| Slice Emittance | \sim 1 - 3 Π mm-mrad |
| Peak Current | > 150 A |
| Energy Spread | 0.2 - 1.5% Selectable |

B. Photo-injector Laser

In order to optimize the efficiency of photo-emission and to have control over the characteristics of the emitted electrons, a photo injector laser which meets exacting specifications and repeatable performance has been installed and completely characterized.

A schematic of the photon seed laser system may be found in [1]. The near collimated beam produced by this system is transported to the CIRFEL system at vault level by turning and steering mirrors with reflectivities optimized for 45 degree incidence and p-polarization. The beam is then expanded in a telescope and then focused with long focal length refractive optics followed by a half wave plate so as to optimize polarized light vector on the cathode. Optical elements to correct the geometrical distortion of incoming beam at the cathode illuminated at 65° to the normal at the cathode surface in the form of a cylindrical lens pair have been installed. An optical element is under fabrication to correct the time spread produced by the off-axis illumination of the cathode.

Initial characterization was carried out on the diode pumped Lightwave Nd-YLF oscillator. An average power output of 240 mW at the exit port of this laser was measured with a calorimetric power meter which has remained constant to better than 1% measured several times since it was installed. The Lightwave oscillator is

phase locked to the RF source (20th sub-harmonic of 2.856 GHz=142.8 MHz) derived from the master oscillator driving the RF Linac. Phase stability measurement was carried out by mixing the RF master oscillator signal and the output of the laser oscillator detected by an Antel fast photo diode. D.W.Feldman of Los Alamos Laboratories participated in this experiment. The phase stability was better than 1 psec. The laser oscillator produces a beam with a zero order Gaussian transverse profile. The Gaussian transverse profile remained stable in position and mode structure for periods of observation of several hours. The mode locked pulses from this oscillator have a duration of 6.7 psec which was verified to remain constant over extended periods of time, with an in-line INRAD autocorrelator. The output spectrum of the laser driven by the internal / external oscillator using an Antel photo diode and a spectrum analyzer showed no spurious frequencies in the laser output.

The seed laser macro pulse is designed to have a ~10 msec flat top. In order to maintain the pulse flatness, a feed-forward correction scheme which involves, sampling the 261 nm laser pulse and adjusting the voltage on the Pockel cell as appropriate, has been implemented using the LABVIEW Control system around which the control of CIRFEL system is configured. The amplitude and phase fluctuations of the RF have been controlled to less than a fraction of a percent and less than fraction of a degree respectively using a slightly different algorithm.

The positional stability of the drive laser was characterized by looking at a focused spot with a CCD camera and an image analyzer software. Laser spot centroid movement was determined to be less than ~25 μm . The spot movement of the transported beam on the cathode location was found to be less than ~45 μm measured over a period of 10 minutes. These measurements were carried out at a dummy location of the cathode as the off-axis specular reflection from Mg was found to be too weak.

III. ELECTRON BEAM CHARACTERISTICS

The principal diagnostics used in the CIRFEL system are the current monitors and the pop-up monitor screens at various locations. The current monitors are situated so as to measure the electron current entering the bend section, the current entering the wiggler and the current leaving the wiggler. Gross aperturing of the beam can be easily detected using these monitors. A pop-up monitor before the 90 degree bend helps in centering the beam to the bend entrance. A pop-up monitor in the middle of two 45 degree bends helps to locate beam in a position appropriate

for the energy. The three pop-up monitors at either end and the middle of the wiggler monitors to maintain the beam in the center of the wiggler. The HeNe alignment laser also illuminates these monitors so that the electron beam can be made collinear with the FEL laser cavity.

A. Effect of improving the flatness of the RF amplitude & phase

Maintaining the flatness of the cavity fields and the RF phase improves the energy spread of the beam. RF field amplitudes have been flattened to less than a fraction of a percent and RF phase to fractions of a degree. This has improved the energy spread dramatically as shown in Fig.1.

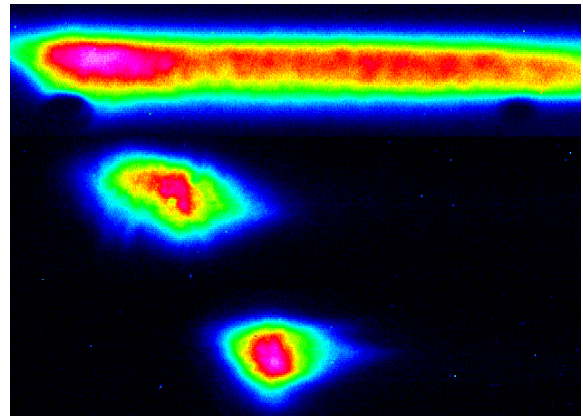


Fig. 1. Electron beam profile on a fluorescent screen in the bend region in CIRFEL. In this composite frame, the TOP profile is that of a beam produced by RF whose amplitude and phase are not flat during the macro pulse. The profile in the MIDDLE is that of beam whose RF macropulse amplitude is flattened to within a fraction of a percent, but its phase not flat. The BOTTOM profile is that one for which both amplitude and phase are flat during the macro pulse.

B. Energy calibration and energy spread of the electron beam

The main diagnostic for energy measurement is the calibrated magnetic field of the bend dipoles and the calibrated electron position monitor screen. Well defined fiducial points imprinted on the screen were used to calibrate the position monitor. Using the calibrated dipole and by producing beams of differing energies, the monitor screen in the middle of the bend was calibrated in terms of energy. The 14.5 mm of monitored reference line in the bend corresponds to 0.54 MeV. This calibration has been used to estimate the energy spread of the beam by measuring the spatial extent of the electron beam on this

monitor, at the appropriate energy. Fig.2 shows the analysis of a typical beam and this does not take into consideration the finite emittance of the beam.

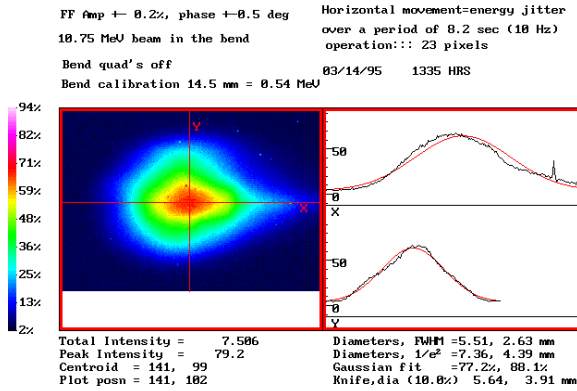


Fig.2 Electron beam profile on a fluorescent screen in the bending region (after the first 45 degree bend) in CIRFEL. The horizontal axis is calibrated in energy

C. Energy jitter of the electron beam

The movement of the electron beam on the bend monitor has been measured using the diagnostic system and the image acquisition & analysis program of Sensor Physics. Using the movie feature of this software, the images are acquired in the framing mode and the software automatically calculates the centroid movement in both axes and adds in a time stamp for each frame. Using this feature the electron spot movement on the bend pop-up monitor screen has been measured. Fig.3 shows the images acquired at 0.3 sec intervals by such a method for a ~11 MeV, 40 mA, 4.75 micro-sec beam. Using energy calibration the jitter in energy of this beam is less than +/- 0.05 MeV.

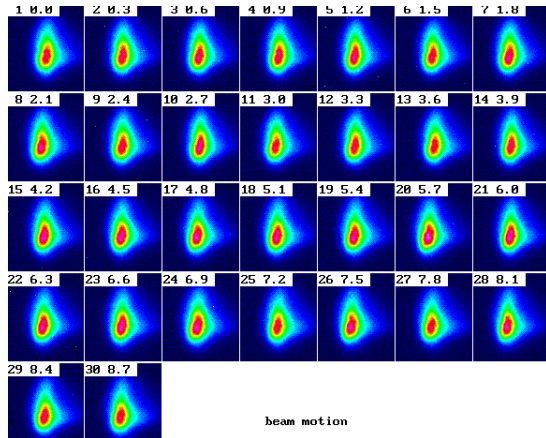


Fig.3. Beam motion in bending plane in framing mode

IV. FEL OPTICAL CAVITY & DIAGNOSTICS

Cavity Parameters of Cirtel for ~10 micron operation has the following parameters:

| | |
|---|----------------|
| Near confocal stable resonator | |
| Wiggler asymmetric with respect to cavity | |
| Cavity length | 3.1494 meters |
| Radii mirrors | 1.4m & 2.19 m |
| Coatings | 8 to 12 micron |
| Raleigh range | 56.9 cm |
| Spot sizes on mirrors | < 5mm |
| Divergence | ~2.4 mrad |
| Waist | 2 mm |

The Photo cathode gun and the booster cavities have been conditioned up to a maximum energy of 12 MeV with stable continuous operation in the ~11.5 MeV range transporting > 1nC of charge through the wiggler with observation of spontaneous radiation. For this energy range using the wiggler parameters the expected optical radiation is in the 12 to 13 micron range where the original dielectric mirrors do not have adequate reflectivities to obtain FEL operation. Presently, the FEL is being equipped with copper cavity mirrors of the same radii of curvature, but with coupling holes to couple out 1 to 2% of the cavity radiation. Efforts are underway in setting up the cavity length exactly to satisfy the synchronicity condition for lasing.

Preliminary emittance measurements by quadrupole scanning of a ~10.5 MeV beam carrying ~1 nC at an optimum but unspecified launch phase with flat RF, phase, and drive laser excitations gives RMS normalized emittances of ~3.5 mm-mrad which agrees with results of MAGIC simulation.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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