

# BEAM LINE DESIGN AT THE MARYLAND INFRARED FREE ELECTRON LASER (MIRFEL)

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## Abstract

The Maryland Infrared Free Electron Laser is being constructed at the University of Maryland, and is expected to lase in the far infrared. The accelerator driving the laser is a 10 MeV linac which is being assembled in an "in-line" configuration. The design work for the accelerator was accomplished using Trace-3D and PARMELA computer simulations. When the accelerator is completed, it will be able to accommodate several additional experimental sections within the beam line itself in order to further study accelerator physics.

## 1 INTRODUCTION

The Maryland Infrared Free Electron Laser has three main components that combine to form the entire system; the RF power source, an electron accelerator, and a wiggler. MIRFEL has a number of unique attributes that make it ideally suited for FIR research, including high peak power ( $> MW$ ), average power near 2 W, short pulse radiation (5 ps), and rapid tunability. Another important feature is the 7 ns pulse separation. Unlike FELs with sub-nanosecond pulse spacing, the pulse spacing in MIRFEL is long enough to allow samples to cool or relax between pulses. Furthermore, MIRFEL incorporates a ps-pulsed Nd:YLF photocathode drive laser that is phase locked to the electron beam and FEL optical output. The drive-laser can produce harmonics at 1.047, 0.524, 0.349, and 0.262  $\mu m$  using amplification and harmonic generation crystals, and can be used for experiments in conjunction with the primary FEL output.

The MIRFEL accelerator is a high-brightness electron source capable of producing electron pulses with energies up to 14 MeV and peak currents in excess of 150 A. The accelerator consists of two separate units, the gun and the booster. The gun is a 9-MeV, 20 cm long, 3 1/2 cell S-band structure (see Fig 1). A 6 mm diameter Mg disk serves as a photocathode [1], but a heated LaB<sub>6</sub> photocathode is planned for future operation.

Downstream from the gun is a 2-cell booster cavity, identical to the central two cells of the gun. This booster can raise the electron energy to 14 MeV. RF power is provided by a single ITT 2960 klystron system with feed forward control [2], amplitude stability of  $\pm 0.1\%$  and phase stability better than 1 degree was achieved for  $2\mu s$  of the pulse duration [1].

This paper focuses on the basic design of the accelerator, which was developed in accordance with space constraints and beam parameter requirements. Particle Beam Optics (PBO) Laboratory [3] and PARMELA [4], two software simulations, were the primary tools used for designing the accelerator subsystem.

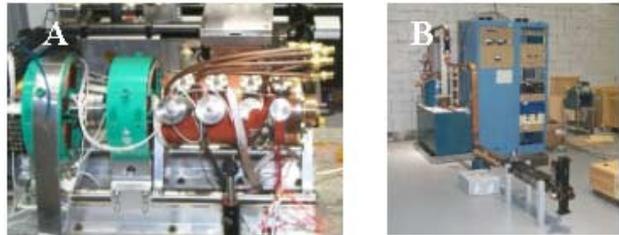


Figure 1 : (A) RF Gun (B) 2856 MHz Klystron

## 2 ACCELERATOR DESIGN

MIRFEL is currently under construction in the High Bay Area at the Institute for Research in Electronics and Applied Physics at the University of Maryland. There are three major considerations that drive the design process.

- In order to make the best possible use of the space available, as well as the desire to produce the highest quality FEL output light, MIRFEL will be built in an in-line configuration. The electron beam is therefore required to travel through a 2mm hole in the upstream mirror of the optical cavity, which corresponds to approximately 1% of the area of the optical mode.
- The accelerator must properly match the beam into the wiggler.
- After the FEL is completed, our group plans to conduct experiments on novel beam diagnostic techniques, different regimes of FEL operation, and other beam physics experiments. A 1m drift section will aid in the setup and conduction of these experiments.

### 2.1 Initial Beam Parameters

As previously mentioned, the electron beam source is a photocathode and 3 1/2 cell RF gun. This section of the accelerator was modeled first using a PARMELA simulation, modified from the one used at the Accelerator

Test Facility at Brookhaven National Laboratory [5]. The initial beam was assumed to take a Gaussian form with a laser pulse length of 5ps and a beam radius of 1mm. The average axial electric field was set at 53.3MV/m. The beam at the end of the gun can be characterized by the parameters shown in Table 1.

Table 1: Beam Parameters at exit of RF Gun

Average Beam Energy	7.6 MeV
Energy Spread	~2%
Emittance (x rms, norm.)	1.0μm
Emittance (y rms, norm.)	1.0μm
Emittance (z rms, norm.)	39.9 deg-kev

Figure 2 shows trace space plots and an x-y plot from the PARMELA simulation at the exit from the RF gun.

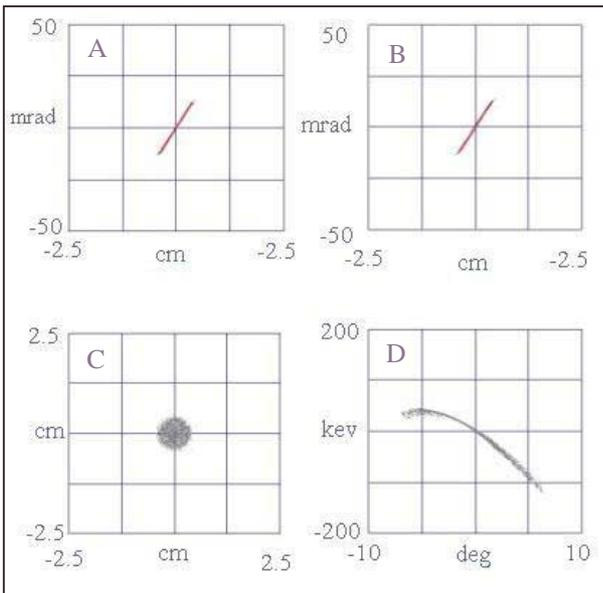


Figure 2 : Trace Space Plots : (A) x-x' (B) y-y' (C) x-y (D)  $\Delta\Phi-\Delta W$ .

### 2.2 Booster Section & Beam Transport

The output from the RF gun must travel through the transport system until it the energy is raised once again by a 2 cell booster section. Next, it must be focused through the upstream optical cavity mirror and finally matched to

the wiggler. Our wiggler provides vertical but no horizontal focusing. Therefore, the horizontal component of the beam will simply come to a waist at the center of the wiggler while the vertical component should pass through with no major oscillations. The matching vertical radius is given by the following :

$$w_y = \sqrt{\frac{\epsilon_{y,n} \sqrt{2} mc}{e B_o}}$$

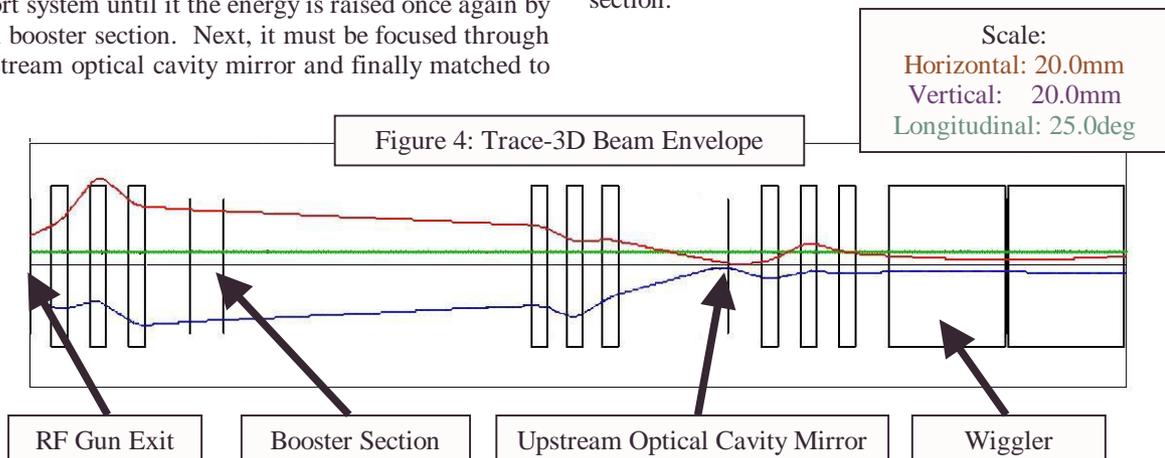
Where  $B_o=1820$  G. The normalized emittance is taken just before the wiggler entrance (See Table 2). This yields a matched beam radius of  $w_y=0.134$ mm.

The data from the exit of the RF gun was provided as initial conditions for the Trace 3-D design. The code was used to find initial placement of quadrupole magnets (see Fig. 3) along the beamline for proper focusing through the system and to model beam behavior through the wiggler.



Figure 3 : MIRFEL Quadrupole magnets

The beam envelopes calculated by the Trace-3D simulation are shown in Figure 4. Note the beam is small as it passes through the upstream cavity mirror and that the beam is reasonably matched through the wiggler section.



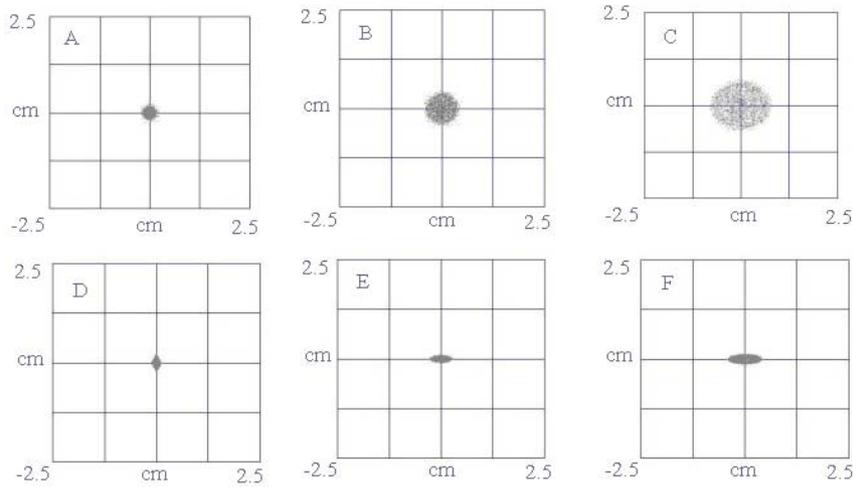


Figure 5 : x-y plots at various points along the beamline. (A) At the photocathode (B) Exit of RF gun (C) Exit of booster section (D) Upstream cavity mirror aperture (E) Wiggler center (F) Wiggler Exit

Next, the transport line was converted into PARMELA code, where the entire beam line could be simulated from the photocathode to the end of the accelerator. While Trace-3D is a linear code, PARMELA is a particle-pushing code that can take non-linear forces into account. Therefore, it was necessary to tweak some of the field gradients in the quadrupoles in order to maintain a similar envelope shape, but significant changes were not necessary. Table 2 shows characteristics of the beam just prior to entering the wiggler.

Table 2: Beam Parameters at entrance to wiggler

Average Beam Energy	11.9 MeV
Energy Spread	~1.0%
Emittance (x rms, norm.)	1.7 $\mu$ m
Emittance (y rms, norm.)	1.4 $\mu$ m
Emittance (z rms, norm.)	66.4 deg-kev

Figure 5 shows a series of x-y plots produced by PARMELA along the accelerator in order to see how the beam propagates through the pipe.

### 3 CONCLUSION

PARMELA and Trace-3D were used in conjunction in order to model the beam from the photocathode through

the entire accelerator and beam transport system and finally through the wiggler at the Maryland Infrared Free Electron Laser (MIRFEL). The results show the beam passing through the cavity mirror and show reasonable matching through the wiggler section. From these simulations, we plan to develop mechanical drawings of the accelerator design to be followed by construction and commissioning of the machine.

### 4 REFERENCES

- [1] I.S. Lehrman, et al. *Proc. SPIE* 2522 (1995) 451.
- [2] R. Hartley, I.S. Lehrman, J. Krishnaswamy. *Nucl. Instr. And Meth. A* 375 (1996) ABS22
- [3] PBO-Lab is a front end for the Trace-3D software distributed by AccelSoft & G. H. Gillespie Associates, Inc.
- [4] PARMELA is developed and distributed by the Los Alamos National Laboratories Accelerator Code Group.
- [5] Z. Parsa, L. Young. *Nucl. Instr. and Meth. A* 318 (1992) 254.