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**TITLE: ELECTRON BEAM SENSITIVITY STUDY OF THE LOS ALAMOS ADVANCED
FREE-ELECTRON LASER BEAMLINE**

AUTHOR(S): S. Hartman, A. Lombardi, R. Sheffield, and T. Wang

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**ELECTRON-BEAM SENSITIVITY STUDY
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Spencer Hartman,** Alessandra Lombardi,

Richard Sheffield and Tai-Sen Wang

Los Alamos National Laboratory

Mail Stop H829

Los Alamos, NM 87545

** University of California at Los Angeles

Dept. of Physics, 405 Hilgard Ave., Los Angeles, CA 90024

ABSTRACT

A sensitivity study that used the particle tracking code PARMELA was performed on the Advanced Free-Electron Laser (AFEL) [1]. The tolerances on the alignment of the beam-line elements and the magnetic-field strengths were examined.

Two base-line linac configurations were determined at the beginning of the study. The electron beam was then matched into the wiggler. The optimized beam-line parameters were varied independently and their sensitivities were judged with the criterion that the free-electron laser (FEL) effective-detuning parameter should not fluctuate more than 10%.

The results of this study set the specifications for the alignment, for the sensitivity of the steering magnets, and for the accuracy of the magnetic field in the quadrupoles and dipoles.

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Proof to be sent to: Alessandra Lombardi, MS H829, Los Alamos National Laboratory,
Los Alamos, NM 87545, U.S.A. Phone (505)667-9426, fax (505)667-0919

ELECTRON-BEAM SENSITIVITY STUDY OF THE LOS ALAMOS ADVANCED FREE-ELECTRON LASER BEAM LINE *

Spencer Hartman,** Alessandra Lombardi,

Richard Sheffield and Tai-Sen Wang

Los Alamos National Laboratory

Mail Stop H825

Los Alamos, NM 87545

** University of California at Los Angeles

Dept. of Physics, 405 Hilgard Ave., Los Angeles, CA 90024

INTRODUCTION

The Advanced Free-Electron Laser (AFEL) [1] is a project at the Los Alamos National Laboratory, that aims to build a compact, high-performance free-electron laser. The high brightness beam required, a less-than- 10π -mm-mrad-emittance, 300-A-peak-current electron beam, will be produced by a photocatode and accelerated to 20 MeV by a 1.2-m-long linear accelerator. An optical beam-line, consisting of seven quadrupoles and two dipoles, will guide the beam from the accelerator to the wiggler. Figure 1 shows the complete beam-line of the AFEL experiment.

In this paper we will present a sensitivity study of the components of the AFEL beam-line. The results of this study set the specifications for the alignment, for the sensitivity of the steering magnets, and for the accuracy of the magnetic field in the quadrupoles and dipoles.

EFFECTIVE DETUNING PARAMETER

The sensitivity of a beam-line specific parameter is defined by the impact of the change of this parameter on the gain in the AFEL interaction.

An indirect measure of the quality of the FEL interaction is the effective detuning parameter [2] which is defined as follows :

$$\Delta\nu = \frac{2\pi h N}{(1 + K_w^2)}((K_w K r)^2 + (\gamma\theta)^2) + \frac{4\pi h N(\gamma - \gamma_0)}{\gamma_0} \quad (1)$$

where

h is the harmonic number

N is the number of wiggler periods

K_w is the wiggler wave-number

K is the wiggler parameter

r is the rms electron-beam radius

γ is the particle energy in rest-mass energy units

γ_0 is the average bunch energy

θ is the injection angle into the wiggler.

The two terms in Eq. (1) represent, respectively, the matching into the wiggler and the energy spread of the beam, which are two determinant quantities for the FEL performance. The quantity $\Delta\nu$ is related to the spontaneous emission intensity spectrum by the relation $(\frac{\sin(\Delta\nu)}{\Delta\nu})^2$.

We should take into account that the ν parameter is a good representation of the FEL interaction only when the electron beam and optical beam overlap completely. Consider figure 2a,b and c : in the first two cases ν is a good representation of the FEL process. In the third case the FEL has a loss in gain because of the mismatch that is not considered in the ν parameter.

To calculate $\Delta\nu$ we first use the particle tracking code PARMELA [3] to simulate the electron dynamics from the photocathode through the accelerator and the transport line,

and we extract the particles canonical coordinates at selected points in the wiggler. Then, with a special postprocessor, we slice the beam into equal-sized bins of the slippage length and calculate average energy (γ) and radius (r) for each bin. When we put these values into Eq. (1), we obtain a $\Delta\nu$ value for each bin; the final $\Delta\nu$ is the average over all the bins.

Beam-line fluctuations tolerated are those that do not change the average $\Delta\nu$ by more than 10% with respect to the base-line case.

PROCEDURE FOR THE NUMERICAL SIMULATION

The simulations were done in three steps : first PARMELA was run to track the beam from the photocathode to the end of the linac. Then the linac parameters were optimized. Finally a sensitivity study was carried out for the accelerating line [4].

Two initial linac configurations were chosen, and the sensitivity of the optics transport line was analyzed.

A schematic layout of the beam-line optics elements is reported in Figure 2. The magnetic-elements field strengths are reported in Table 1. The physics underlying the design of this beam-line can be found in [5].

The magnetic field strengths of the quadrupoles and dipoles were varied independently.

The transverse displacements were done with the quadrupole doublets being moved as a single structure while the two dipoles and the fifth quadrupole (Q_5) were varied independently. The doublets were treated as a single unit because they will be permanently mounted together on the same support structure and once placed they should not move relative to each other. However, the effects of rotating a single quadrupole was also calculated. Only a single parameter was varied for each sensitivity run. The calculations were carried on the third harmonic of the wiggler ($\lambda=1.2$ mm); the tolerance for the first harmonic is looser as the beam emittance requirements are less strict.

The beam properties and wiggler parameters are given in Table 2.

The simulations did not incorporate the effect of thermal emittance and wiggler focusing. These two factors should not appreciably affect the beam-line sensitivity.

Also, the simulations did not take into account the possible loss in gain due to a not perfect overlapping between the optical and the electron beam. To give an estimate of this effect, we calculated the position of the centroid and the radius of the beam along the wiggler, and we compared them to the position and dimension of a gaussian optical beam. We found that in the worst case we suffered a loss in the overlapping area, on the third harmonic, of less than 1/10. We think that we can correct this problem with steering magnets (see Figure 1). However this problem is more dramatic on higher harmonics.

RESULTS

Table 3 summarizes the results of approximately 150 PARMELA runs and should give a reasonable idea of the critical parameters that need special attention in the set up of the electron-beam transport optics, i.e., micropositioning of elements, setting field strengths, minimizing element skew, and so forth.

The x-direction or direction of dispersion is much more sensitive than the y direction. These results indicate that we must align the beam-line elements to within at least 100 μm or better. Also, taking into account the centroid displacement we must steer the beam with an accuracy of the order of 50 μm to ensure a complete overlap between the optical and electron beam.

We also tried another linac configuration where the solenoid strength was changed by 10% with respect to the previous case. In this beam-line configuration the AFEL was extremely sensitive. This was evidenced by losing the beam when we changed the B-field strength in the first quadrupole by only 5%. This abrupt loss of the beam lead us to the conclusion that this beam-line is too sensitive and further study is not worthwhile.

CONCLUSIONS

To limit the fluctuation in the AFEL $\Delta\nu$ parameter to less than 10% on the third harmonic, the transverse alignment of the beam-line elements needs to be done to within 100 μm , with the added requirement that the beam can be steered and monitored to within 50 μm . The magnetic-field strengths should be stable to within 0.1% and the rotation tolerance about the z-axis of the magnetic elements is 0.1 $^\circ$. However the two quadrupoles that constitute the first doublet should be aligned to within 0.01 $^\circ$.

REFERENCES

- [1] K.C.D. Chan et al., " Los Alamos advanced Free-Electron Laser", these proceedings.
- [2] W.B. Colson, G. Dattoli, and F. Ciocci, "Angular gain spectrum of free-electron lasers", *Phys. Rev. A* **64**,2 (1985).
- [3] PARMELA is a computer code written by K. Crandell and is available from the Los Alamos Accelerator Code Group, AT-7, ms H829, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.
- [4] R.L. Sheffield, "Sensitivity study of the AFEL accelerator", Los Alamos National Laboratory technical memorandum AT-7:91-TM-5.
- [5] T.F. Wang et al., " Design of the e-beam transport for the AFEL", these proceedings.

FIGURE CAPTIONS

Fig. 1. Schematic of the AFEL experiment beam-line.

Fig. 2. Relative positions of the optical and electrical beam in the wiggler.

Fig. 3. Schematic of the AFEL beam-line used in the simulations.

Table 1

Magnetic-field value in the base-line case.

Q_1 4730 G/cm

Q_2 -3690 G/cm

Q_3 4327 G/cm

Q_4 -2680 G/cm

D_1 3521 G

Q_5 1517 G/cm

D_2 3521 G

Q_6 -3011 G/cm

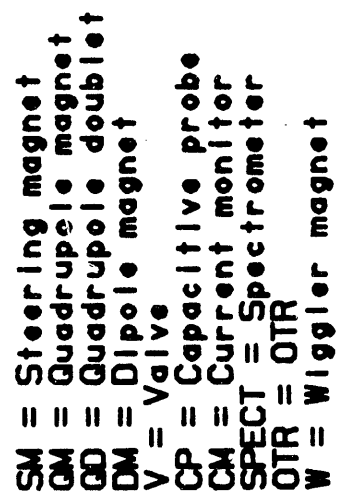
Q_7 3339 G/cm

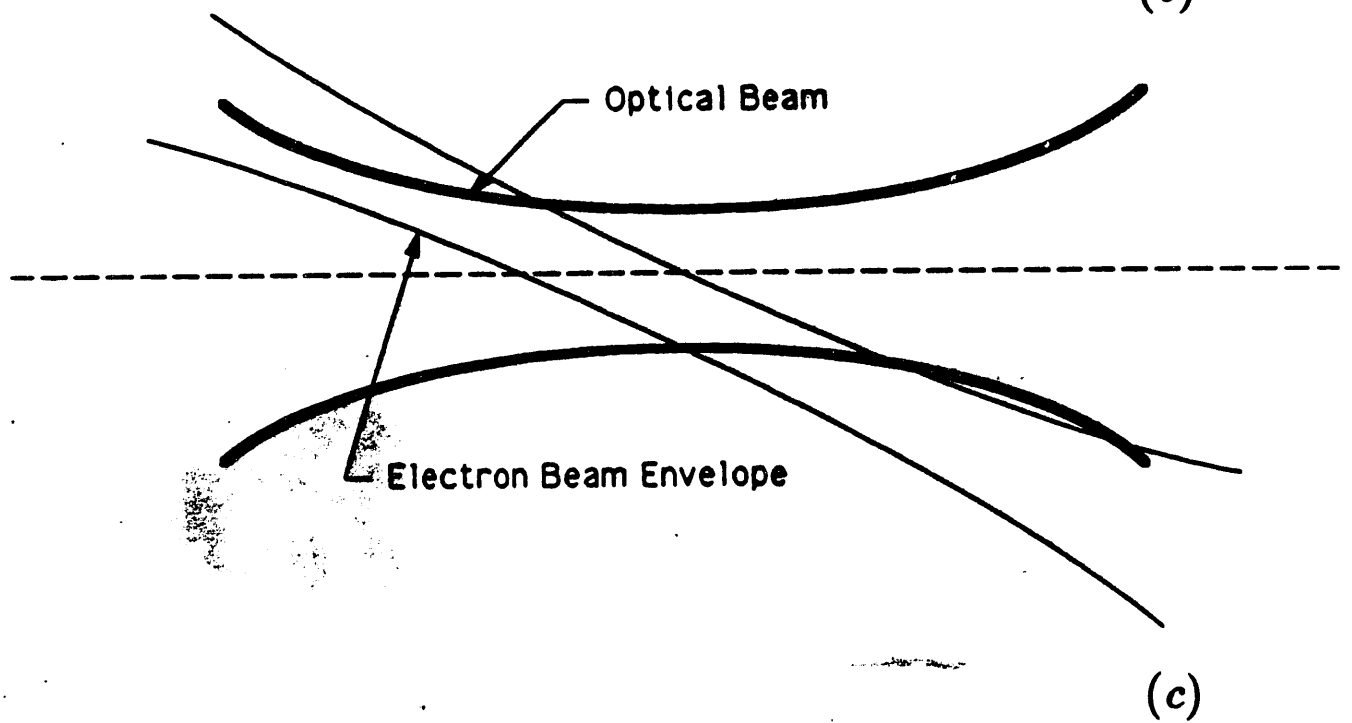
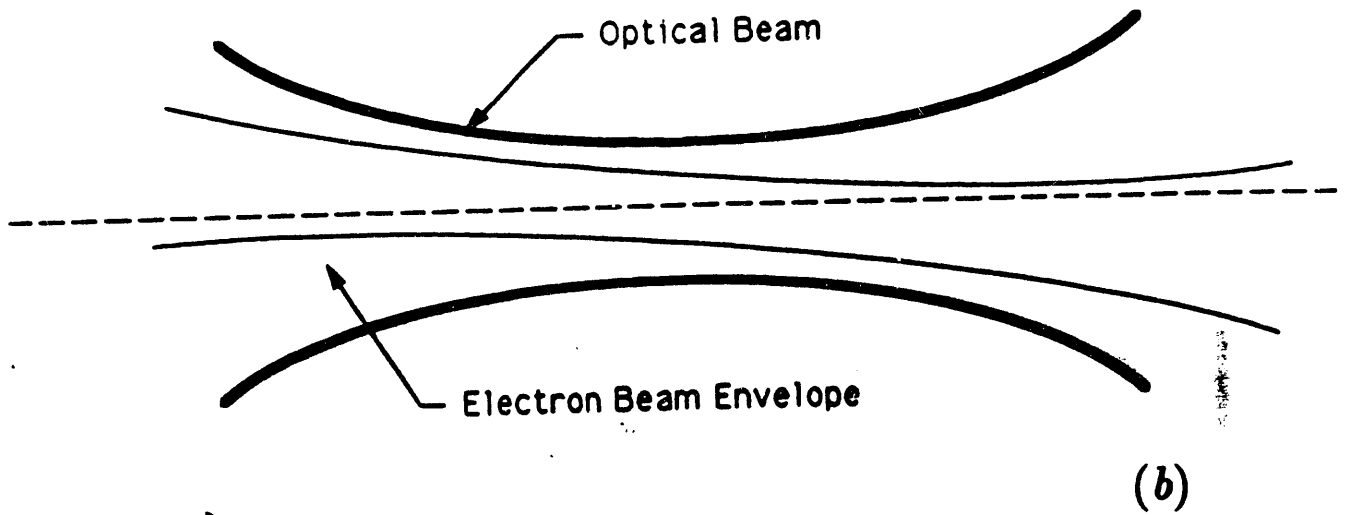
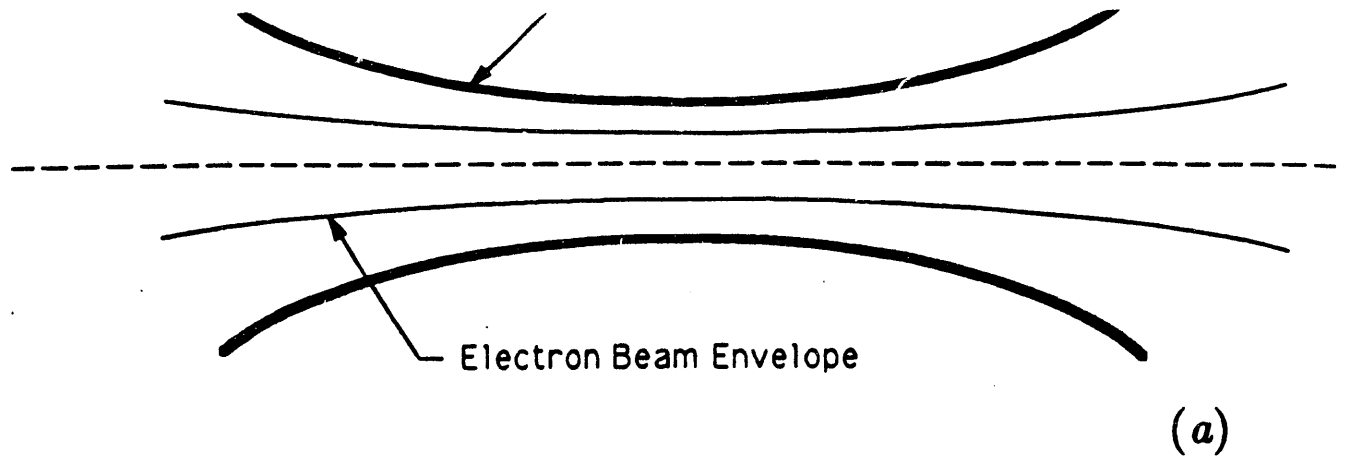
Table 2
FEL parameters.

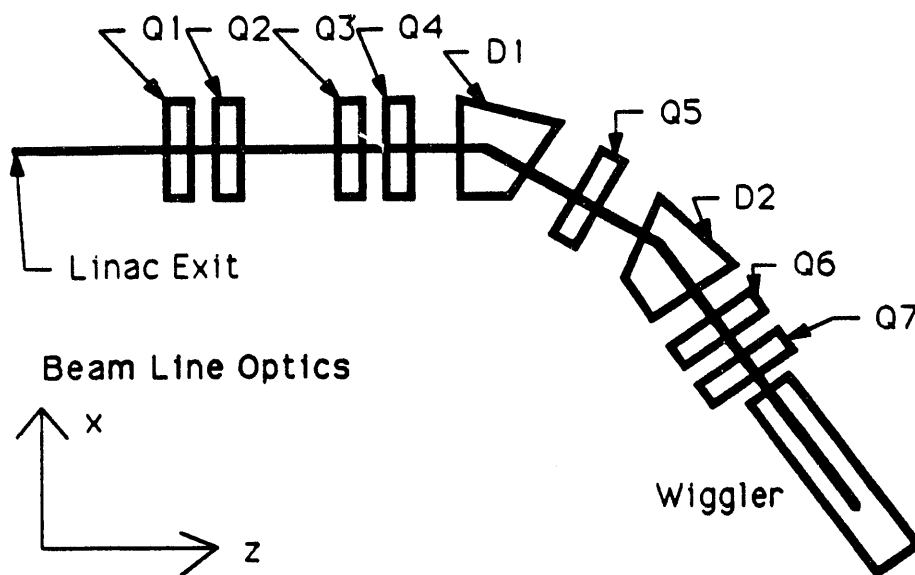
Wiggler parameter	0.7
Wiggler period	1 cm
Number of periods	20
Harmonic	3
Gamma ave.	41.4
Wavelength	1.2 mm
y-emit (90%)	5.4 mm-mrad
x-emit (90%)	6.7 mm-mrad
r-rms	0.022 cm

Table 3
Beam-line tolerances

	B-field ($\pm\%$)	x-mis (μm)	y-mis (μm)	rot (deg)
Q1	2	100	300	0.01
Q2	0.5			0.01
Q3	0.1	100	600	0.1
Q4	0.5			0.1
D1	10	400	400	0.1
Q5	0.1	100	400	0.1
D2	5	400	400	0.1
Q6	2	400	300	0.1
Q7	2			0.1
Linac		600	600	0.1







END

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