FIRST ORDER DESIGN STUDY OF AN ACCELERATOR BEAMLINE FOR THE PEARL FEL

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Abstract

The Pan-Oceanic Environmental and Atmospheric Research Laboratory (PEARL) consortium has proposed the deployment of a ship-based FEL facility in order to carry out advanced atmospheric and environmental research for a variety of applications. The FEL is intended to have an optical output from approximately 20 microns down to 1/3 micron, with up to 1 kW average power. The accelerator will operate over a wide range of beam currents and energies to meet these goals. Clearly, the proposed shipboard FEL must meet many design constraints in compactness and efficiency. The accelerator beamline, upstream of the FEL resonator, includes a 4.5 MeV rf gun, pulse length compression chicane, and four (4) 1.26 meter long traveling wave (TW) accelerator sections. First order focusing along the beamline is provided by quadrupole magnets. First order beam dynamics for this beamline are studied using TRACE 3-D with a self-consistent TW accelerator model incorporated into it. Parametric studies of current and beamloading effects on accelerator efficiency and beam transport are performed. Beamline layouts, taking into account the physical dimensions and operating parameters of the equipment will be studied to determine the baseline beamline design for further, higher order simulations, on the way towards an optimized design.

1 THE PEARL FEL

The PEARL consortium has proposed use of a powerful lidar system [1-3] for application to the problems of remote sensing and pollution monitoring. Air quality is affected by emissions of NO_x, CO, CO_2, SO_2, hydrocarbons, CFCs, Ozone, and aerosols, etc. In addition there is an interest in detecting illegal drug manufacturing, chemical and biological warfare agents, and clandestine nuclear tests. Concentrations of the emissions of interest range from ppb to ppm, with a need for temporal and spatial resolution. Remote detection lidar processes available include Rayleigh scattering, Mie scattering, Raman scattering, absorption, and DIAL (differential absorption of two laser lines).

The FEL at the core of this lidar system is intended to have an optical output from approximately 20 microns down to 1/3 micron, with up to 1 kW average power. Macropulses of 3-5 microseconds, average currents of hundreds of milliamperes, and electron beam energies ranging from 20 MeV to 120 MeV are being considered as operating parameters of the accelerator/driver. In addition, high peak power requirements translate to a high micropulse current, 500-1000 Amps over 2-4 picoseconds. To begin translation of earlier system studies into specification of an accelerator beamline, several first order designs are being compared to gain insight into the problem. The remainder of this paper discusses four beamlines looked at using TRACE 3D. This version of TRACE 3D has been modified to incorporate traveling wave accelerator structures, both constant gradient and constant impedance [4].

2 THE BEAMLINES

The baseline accelerator design is taken from the 1 kW FEL concept of Cover, et. al. [5]. A 1.5 cell rf gun produces a 4.5 MeV electron beam [6]. This beam is

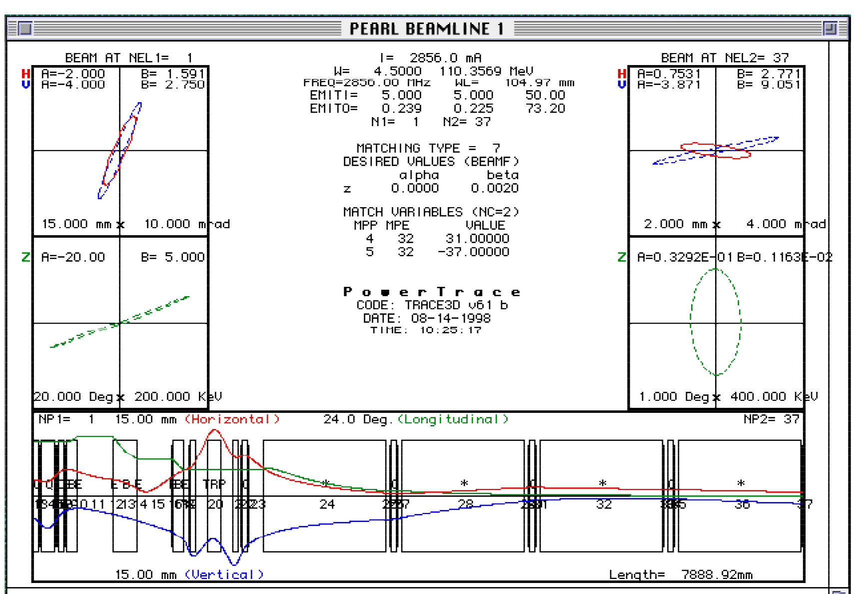

Figure 1: The Baseline PEARL Magnetic Chicane Buncher and Four Accelerator Structures

bunched in a variable magnetic chicane consisting of two 5" diameter dipole magnets placed about a large central magnet. The central magnet was designed to provide a path length equal to the combined path lengths of the two outside dipoles for any angle of entry. Bend angles up to 40 degrees can be accommodated, giving great flexibility in pulse compression. The beam is matched into the first of four 1.26 meter accelerator sections, which are derived from the SLAC 3 m structure. Three of them incorporate higher order mode outcouplers to extend BBU thresholds and limit emittance growth. Quadrupole magnets are placed in between the structures to provide focusing. Figure 1 illustrates this baseline, with a beam of 1 nC every eighth rf bucket accelerated to 110 MeV. Initial conditions for the TRACE 3D simulations are given in Table 1.

Table 2 summarizes the parameters for the different beamlines. Two beamlines use chicanes and two use six accelerator structures. This preliminary study indicates that, with the option to select phase lag for each accelerator structure individually, a chicane buncher is useful, but causes some emittance growth. However, a shorter, <20 psec pulse is probably needed out of the rf gun if the chicane is to be eliminated. Power requirements for the four beamlines are: 112, 104, 79, and 77 MW respectively.

Each beamline transports and accelerates the initial beam (see Table 1) to a final energy of 110 MeV. Parameters have been chosen to obtain this final energy and an upright longitudinal phase space ellipse at the end of the beamline. Table 3 summarizes final emittances and pulse lengths.

3 CONCLUSIONS

The four beamlines examined indicate that shorter and/or lower power alternatives can meet the operating parameters needed for PEARL. A chicane buncher provides greater flexibility at the expense of emittance growth. Future analysis will extend these preliminary results through higher order modeling.

Table 1: Initial Beam Parameters

Beam Kinetic Energy	4.5 MeV
Macropulse Beam Current	357 mA
Micropulse Charge	1 nC
Initial Pulse Length	20 (no ch.) 30 psec (w/ch.)
Correlated Energy Spread	125 - 210 keV
Longitudinal Emittance (z)	50 π deg-keV (eq. unif.)
Transverse Emittance (x,y)	5 π mm-mrad (eq. unif.)

Table 3: Final Beam Parameters

z-emittance (π deg-keV)	73	51	86	51
pulse length (psec)	0.6	1.0	1.0	1.0
x-emittance (π mm-mrad)	0.24	0.23	0.24	0.23
y-emittance (π mm-mrad)	0.23	0.23	0.23	0.23

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Table 2: Beamline Parameters; chicane is specified by initial bend angle (deg.), accelerator structures by initial gradient (MV) and phase lag (deg.).

Beamline #	Chicane	Acc1	Acc2	Acc3	Acc4	Acc5	Acc6
1	26°	26.5/-15.6°	29/-30°	31/-37°	31/-37°	----------	----------
2	----------	15.8/-11.8°	30/-30°	32/-20°	32/-20°	----------	----------
3	28°	18/-16°	12.6/-12°	12.6/-12°	24.5/-20°	24.5/-20°	24.5/-20°
4	----------	13.5/-10°	17.3/-19.2°	21.7/-25°	21.7/-25°	21.7/-25°	21.7/-25°

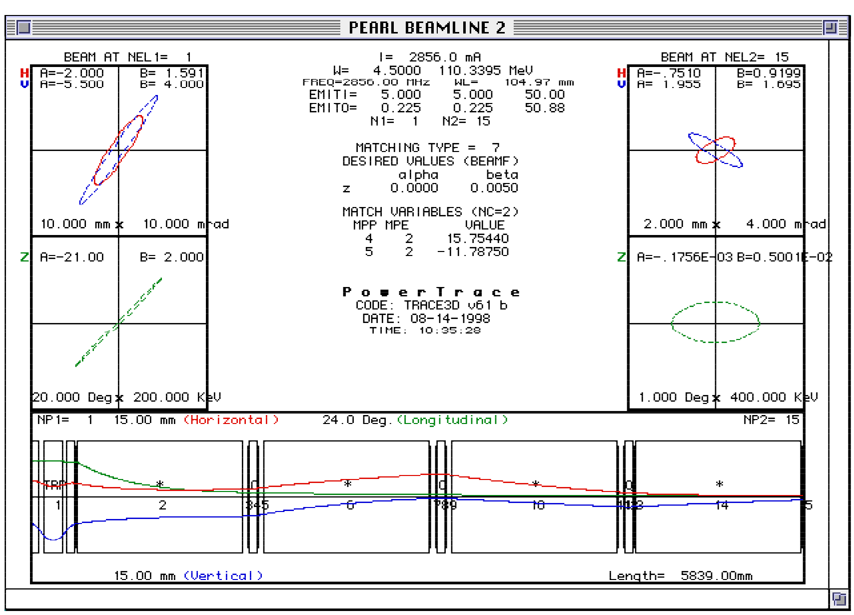

Figure 2: Pulse Compression with Four Accelerator Sections

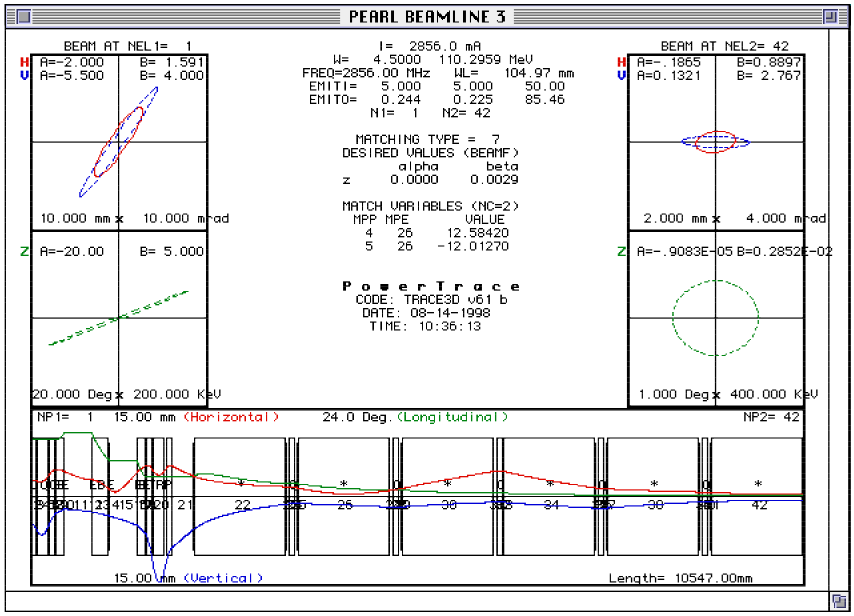

Figure 3: Pulse Compression with Magnetic Chicane Buncher and Six Accelerator Sections

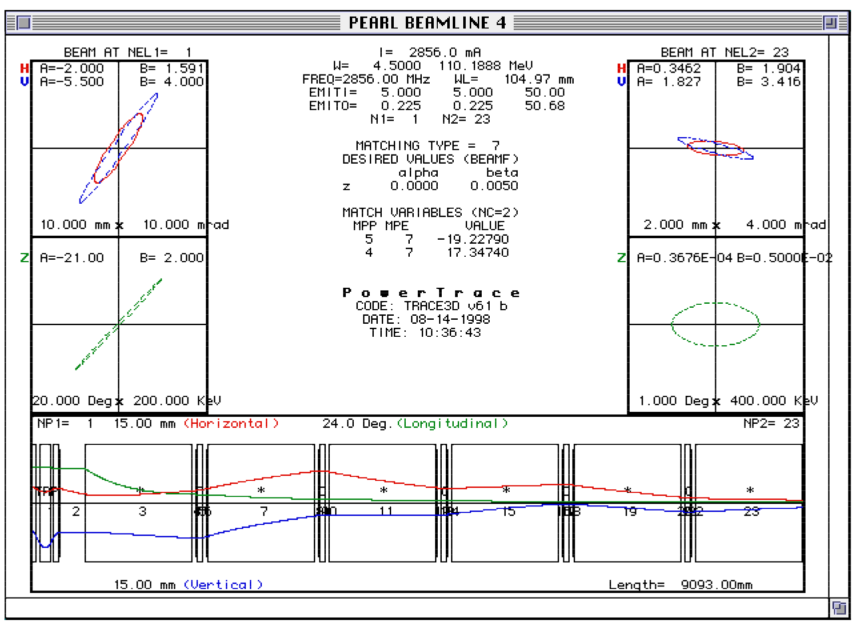

Figure 4: Pulse Compression with Six Accelerator Sections

information on the applications of this technology. Calculations were performed with the PowerTrace™ [7] implementation of TRACE 3D. This work was supported in part by G. H. Gillespie Associates, Inc., Arcata Systems, and the U. of Hawaii.

REFERENCES

[1] J. Madey, R. Burke, C. Helsley, S. Sharma, C. K. Patel, D. Tratt, M. Kennedy,"The PEARL Initiative: Applications of FEL Technology in Support of Atmospheric Research and Remote Sensing", 1998 Int.'l FEL Conf. to be published in NIM A.

[2] C. K. Patel, S. Sharma, C. Helsey, R. Burke, D. Tratt, and R. Collins, "Laser Development from Carbon Dioxide to Free Electron and Their Applications to Remote Sensing and Pollution Monitoring", 19'th Int'l. Laser Radar Conference, Annapolis, MD, July 6, 1998.

[3] S. Sharma, C. Helsley, R. Burke, D. Tratt, and R. Collins, C. K. Patel, "Ship-based Free Electron Laser (FEL) LIDAR for Oceanic and Atmospheric Research", PACON INTERNATIONAL 1997.

[4] M. Lampel, "A Self-Consistent Beam Loaded Traveling Wave Accelerator Model for Use in TRACE 3D", Particle Accelerator Conf., Vancouver, BC, 1997.

[5] R. Cover, G. Bennett, R. Burke, M. Curtin, M. Lampel, G. Rakowsky, J. Quant. Elect. **27**, pp2598-2604, Dec. 1991.

[6] M. Curtin, M. Lampel, J. Hall, R. Burke, R. Cover, "Initial Results from the Rocketdyne Photocathode RF Injector", 16th Int.'l FEL Conf., Stanford, 21-26 Aug. 94.

[7] PowerTrace™ is available from AccelSoft Inc.