Title
The 50 MeV Beam Test Facility at LBL

Author
Leemans, W.

Publication Date
1993-05-01

LBL-33308
UC-414

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

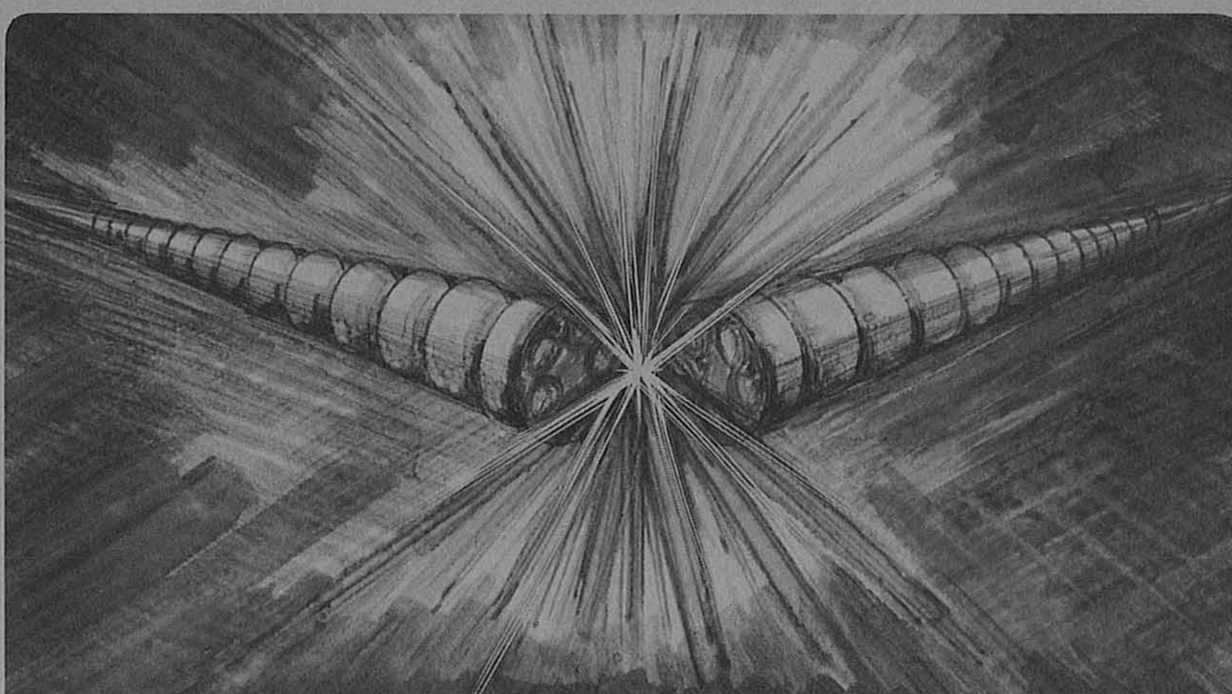
Accelerator & Fusion Research Division

Presented at the IEEE Particle Accelerator Conference, Washington, DC, May 17–20, 1993, and to be published in the Proceedings

The 50 MeV Beam Test Facility at LBL

W. Leemans, G. Behrsing, K.-J. Kim, J. Krupnick, C. Matuk, F. Selph, and S. Chattopadhyay

May 1993



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

The 50 MeV Beam Test Facility at LBL*

W. Leemans, G. Behrsing, K.- J. Kim, J. Krupnick, C. Matuk, F. Selph, and S. Chattopadhyay
Lawrence Berkeley Laboratory
1 Cyclotron Road, Berkeley, CA 94720 USA

Abstract

A new beam line, expected to be built by September 1993, will transport the 50 MeV electron beam from the ALS LINAC into an experimental area to support various R&D activities in the Center for Beam Physics at LBL. A variety of experiments are planned involving the interaction of such a relativistic electron beam with plasmas (plasma focusing), laser beams (generation of femtosecond X-ray pulses) and electromagnetic cavities (Crab cavities etc....). The beam line is designed using the measured emittance and Twiss parameters of the ALS linac. It accommodates the different requirements of the various experiments on the electron beam properties (charge, energy, pulse length) and on the handling of the beam before and after the interaction point. Special attention has also been given to incorporate diagnostics for measuring the beam properties (such as the electron energy, bunch length and charge) needed in the interpretation of the experiments.

I. INTRODUCTION

The Advanced Light Source (ALS) [1] at LBL has a 50 MeV linac, a booster ring which increases the electron energy to 1.5 GeV and a storage ring which is expected to need refilling every 6 - 8 hours. In between refills the 50 MeV electron beam will be transported into an experimental vault named the Beam Test Facility (BTF), to be operated under the auspices of the Center for Beam Physics at LBL in support of its experimental R&D program. We will conduct a variety of experiments involving the interaction of the relativistic electron beam with plasmas (plasma lens focusing), laser beams (beam diagnostic and generation of femtosecond X-ray pulses) and RF-structures. The main linac parameters are given in Table 1. The lay-out of the BTF-line is shown in Fig. 1.

Maximum Energy	50 MeV
Charge	1-2 nC/bunch
Bunch Length (σ_z)	10-15 ps
Emittance rms (unnorm)	0.3 mm-mrad
# bunches/macropulse @ 125 MHz	1 - 10 (max 100)
Macropulse rep. rate	1 - 10 Hz

Table 1: ALS Linac parameters

A first 108° bend uses a 22° dipole magnet (BX) to deflect the linac beam from its usual path towards the booster ring, into the BTF-line, and two 43° dipole magnets (B1 and B2) to bend the beam into a transport tube through a concrete shielding wall. Three quadrupoles (Q1, Q2, Q3) located between BX and B2 are tuned to make the line achromatic after B2.

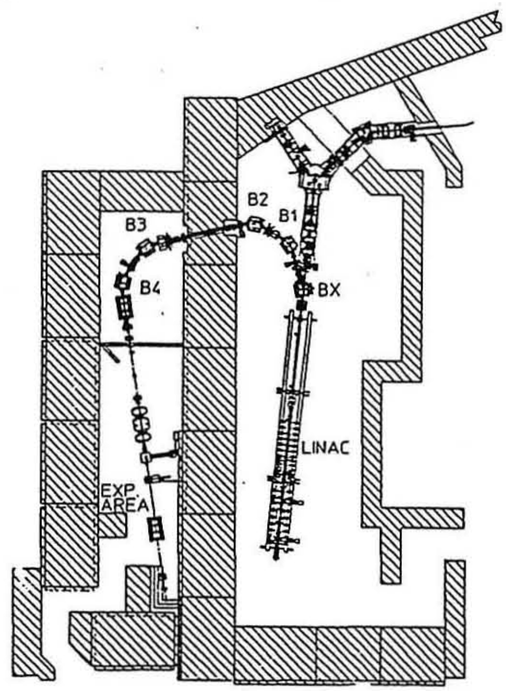


Figure 1: CAD lay-out of the BTF-line

A second 86° bend uses two 43° dipole magnets (B3 and B4) and a quadrupole doublet Q6. Using the Q4 and Q5 doublets upstream of this bend, the beam can be collimated and transported into this bend or focused onto a Cerenkov radiator, located in a diagnostic box, to measure the temporal bunch profile. The second bend is tuned to be achromatic after B4. A telescope consisting of two quadrupole triplets (Q7 and Q8) will allow a wide range of transverse beam sizes to be delivered to the experiments. Due to a slight non-isochronicity of the line, the electron bunch is expected to lengthen about 10 % for a momentum spread of 0.1 %. The vacuum chambers in the 43° bending magnets have been outfitted with a 1" diameter beam pipe tangential to the beam orbit to allow a laser beam to be brought onto the e-beam path.

II. MAGNETIC LATTICE DESIGN

The design of the magnetic lattice of the BTF-line has been done with the code TRACY [2], is based on the measured magnetic properties of the dipole and quadrupole magnets and uses the measured Twiss parameters and beam emittance of the linac. [3] The design goal was for the lattice to accommodate the different requirements set forth by the plasma lens and X-ray source experiments on the electron

* This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

beam, before and after the interaction point. Next we briefly discuss the experiments and the required electron beam parameters.

A. Plasma Lens Experiment

Aside from having the potential to enhance luminosity in future linear colliders, plasma lenses could be useful as small f-number lenses for tightly focusing relativistic beams of moderate energy. The scope of the plasma lens experiment is to study the properties of plasma lenses in both overdense and underdense (in particular the adiabatic lens) regimes.[4] Emphasis will be on resolving important issues such as time response of the lens, lens aberrations and shot-to-shot reproducibility. Using an envelope model, we have determined the plasma requirements (density, length and location) and the beam requirements (waist size, location, charge) which will allow us to study the different regimes. The plasma source will be isolated from the high vacuum transport line using Be-foils. The plasma will be created through multi-photon ionization. The plasma length will be varied from 10 to 35 cm, the density from 10^{11} - 10^{14} cm^{-3}. The e-beam will be focused to a spot with a β-function varying from 0.02 m to 0.4 m. The beam profile at different locations behind the lens will be measured by temporally and spatially resolving the Cerenkov light cone [5] produced when the electron beam hits a thin quartz radiator. The Q9 quadrupole triplet will transport the electron beam onto a beam dump. The optimized lattice is shown in Fig. 2. The graphics were generated with LATTICE. [6]

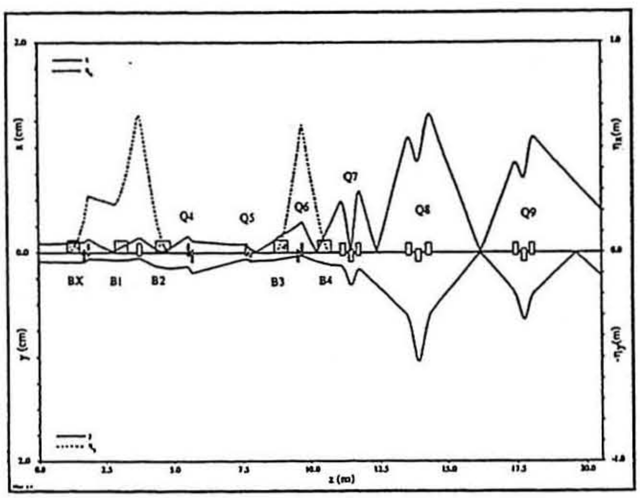


Figure 2: Optimized lattice for the plasma lens experiment.

B. Orthogonal Laser-Electron Beam Scattering Experiment

It is well known that when a photon beam collides with a relativistic electron beam, radiation upshifted in frequency by a factor proportional to γ^2 will be generated through a process named Thomson scattering.[7] Here γ is the Lorentz factor. The pulse duration in a head-on collision will be given by the longer of the laser or electron pulse duration. The electron pulse duration is at least a few ps (σ_z = 10-15 ps for our case) for typical accelerators. It has recently been proposed [8] to generate much shorter pulses of upshifted radiation by using 90° incidence. The optical pulse width is then determined by the longer of the incident optical pulse width and the transit time across the electron beam focus. In this orthogonal scattering geometry, the upshift of the radiation is given by 2 γ^2 and the divergence angle by $1/\gamma\sqrt{N}$. The laser beam acts as an electromagnetic undulator with N the number of electromagnetic oscillation cycles during the transit. In pricnciple, the electron beam size can be determined by measuring the divergence angle of the radiation.

The goals of the X-ray source experiment are twofold: 1) to develop technology towards measuring beam sizes relevant to future linear colliders and 2) to develop technology towards the generation of 1 Å, 30 fs pulses delivering 10^{12} photons/s for study of ultra-fast phenomena. In the present experiment we will collide, a high intensity (10^{16} - 10^{17} W/cm^2), ultra-short (200 - 300 fs) pulse from a Ti:Al_2O_3 laser (0.8 μm) at 90° with the electron beam The lattice has been optimized to give an electron beam waist of 35 μm at the interaction point. This will generate a 0.4 Å X-ray pulse with 300 fs duration in a cone angle of 1.5 mrad, containing about 3 x 10^5 photons. A 90° C-magnet is utilized to separate the particle and photon beams after the interaction point. The optimized lattice is shown in Fig. 3.

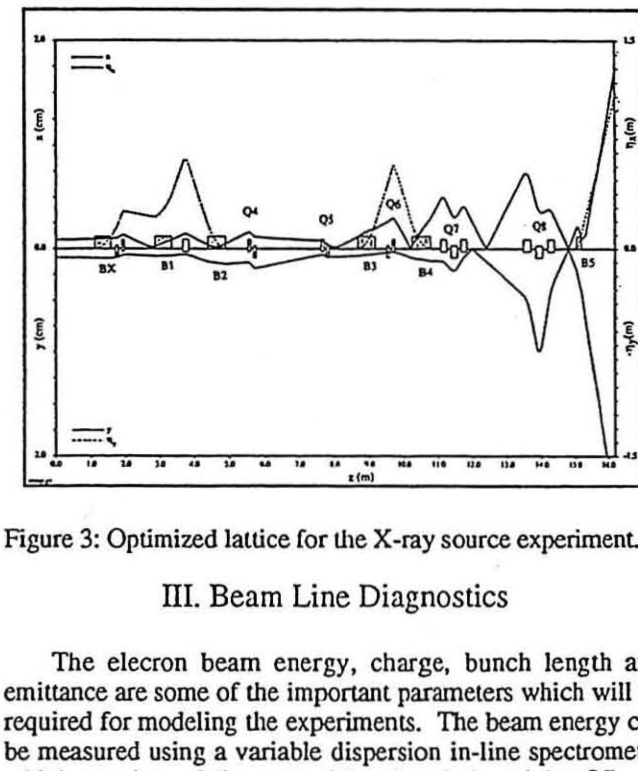


Figure 3: Optimized lattice for the X-ray source experiment.

III. Beam Line Diagnostics

The elecron beam energy, charge, bunch length and emittance are some of the important parameters which will be required for modeling the experiments. The beam energy can be measured using a variable dispersion in-line spectrometer which consists of the second bend and the triplet Q7. A horizontal collimator is located in the object plane and a fluorescent screen/TV module is located in the image plane. The charge will be measured non-destructively with an integrating current transformer. The bunch length will be measured by time resolving the Cerenkov light emitted when the electron beam transits a thin quartz plate. The beam emittance will be measured at two locations: 1) entrance to the BTF-line and 2) exit of the plasma lens. At the former locations the lens strength of an upstream quadrupole triplet is varied while the beam size is monitored on a fixed fluorescent screen. At the latter location the Q8 triplet strength is fixed but a fluorescent screen or Cerenkov radiator is scanned along the beam direction.

The electron beam position along the beam path will be monitored non-destructively with beam position monitors made of high bandwidth pick-up buttons with a measured rise time of 16 ps. Fluorescent screens can be dropped into the beam path at 5 different locations for visual inspection of the beam profile and position, and to aid in the tuning of the achromatic sections. The spatial resolution with the present equipment has been measured to be about 20 μm.

IV. Power Supply Specifications and Timing Issues

The laser and e-beam alignment tolerances and the need for reproducibility in the plasma lens experiment put tight constraints on the shot-to-shot movement of the beam in the transverse and longitudinal directions. Current ripple in the supplies powering the bend magnets and the quadrupoles will respectively cause the beam to move in the horizontal plane and the focus to move back and forth around the optimum interaction point. A detailed study of the beam dynamics has determined that the critical supplies, those powering the dipole magnets and the quadrupole triplets Q7 and Q8 require a current stability of a part in 10^4. [9] With this power supply performance the main limitation stems from bunch-to-bunch energy variation due to beam loading in the 3 GHz accelerator structure. To increase the X-ray flux, we are considering colliding one single laser pulse with many electron bunches, separated by 8 ns, within the same macro-pulse. However, without beam loading compensation, the bunch to bunch energy variation is on the order of 0.8 %. This would cause the waist to move by as much as 10 Rayleigh ranges, thereby severely reducing the interaction efficiency. A beam loading compensation scheme based on phase adjustment of the RF signal fed to the 3 GHz accelerator structure will be tried out this spring and should reduce this an order of magnitude.

In addition, the orthogonal scattering experiment requires accurate synchronization between the laser and the electron beam. Since the linac utilizes a thermionic gun as opposed to a laser driven photocathode, synchronization is more difficult to achieve. An upper limit [10] for the timing jitter has been established at ± 10 ps, by triggering a Tektronix SCD5000 digitizing scope with the signal from a fast rise time (16 ps) pick-up button and monitoring the movement in time of the zero-crossing of the RF-signals which are fed to the first two subharmonic buncher cavities (125 and 500 MHz respectively) The laser can therefore be synchronized with respect to the 125 MHz RF-signal.

V. Status of Construction

The design of the BTF-line is nearing completion. Construction is progressing on schedule and is expected to finish September 1993. Commissioning will take place during Sept./Oct. 1993 with the first experiment scheduled for Nov. 1993.

VI.Summary

We have reported on the design of the Beam Test Facility which will utilize the 50 MeV ALS linac to conduct a variety of experiments in support of the experimental R&D for the Center for Beam Physics at LBL. The magnetic lattice was optimized for a plasma lens experiment and an experiment on orthogonal scattering of a laser beam off the electron beam to generate femto-second X-ray pulses. The optimization was carried out using the measured Twiss parameters and emittance of the linac and the measured magnetic properties of the beam line components. The stringent requirements set forth by both experiments on the transverse and longitudinal beam position necessitated a detailed analysis of power supply stability. Measurement of the bunch-to-bunch beam energy variation indicates that beam loading compensation will be required when attempting to increase the X-ray yield by colliding one single laser pulse with multiple bunches in a macro-pulse.

A variety of beam diagnostics will be implemented to allow measurement of the various beam parameters relevant in the interpretation of the experiments. Experiments are expected to commence during the fall of 1993.

VII. Acknowledgments

The authors want to thank J. Bengtsson for having made available the code TRACY, taking the time to teach one of the authors (W.L.) its power and elegancy and for his guidance in the design of the line and analysis of tolerances. We also thank Barry Bailey for coordinating all electrical work, the ALS operators for their help with the beam property measurements, J. Hinkson for his contributions to the evaluation of the beam line diagnostics, E. Wallace for helping with the design and construction of the plasma lens experiment and the Cerenkov diagnostic, Rick Donahue for having calculated the shielding requirements and L. Stout for his contributions to the initial lay-out.

VIII. References

[1] "1-2 GeV Synchrotron Radiation Source", Conceptual Design Report, LBL-PUB 5172 Rev., 1986.
[2] J. Bengtsson, E. Forest, and H. Nishimura, unpublished.
[3] J. Bengtsson, W. Leemans and T. Byrne, these proceedings.
[4] W. Leemans, A. Sessler, and S. Chattopadhyay, LBL-ESG Tech Note-199.
[5] Y. P. Chong et al., Proceedings 1989 PArt. Acc. Conf., 89CH2669-0, 1493 (1989).
[6] J. Staples, LBL - 23939, June 1987.
[7] See L. R. Elias, Phys. Rev. Lett. **42**, 977 (1979) and references therein.
[8] K.-J. Kim, S. Chattopadhyay, and C. V. Shank, LBL-33074.
[9] W. Leemans and J. Bengtsson, LBL-ESG Tech Note-233.
[10]The actual timing jitter is probably smaller, as the measured value equals the manufacturer's specification of the internal scope trigger jitter.