Presented at the XVth International Conference on High Energy Accelerators, Hamburg, Germany July 20-24, 1992

Conf-920706--17

BNL-47784

THE BROOKHAVEN NATIONAL LABORATORY ACCELERATOR TEST FACILITY

Kenneth Batchelor
Brookhaven National Laboratory
Upton, New York 11973 USA

BNL--47784

DE92 019247

ABSTRACT
The Brookhaven National Laboratory Accelerator Test Facility comprises a 50 MeV travelling wave electron linear accelerator utilizing a high gradient, photo-excited, radiofrequency electron gun as an injector and an experimental area for study of new acceleration methods or advanced radiation sources using free electron lasers. Early operation of the linear accelerator system including calculated and measured beam parameters are presented together with the experimental program for accelerator physics and free electron laser studies.

1 INTRODUCTION

The Accelerator Test Facility is a laser/electron linear accelerator designed to produce high brightness electron beams of 50 MeV to 100 MeV energy for a user program to study advanced linear acceleration techniques. It also provides a source of electrons suitable for the study of advanced radiation sources based on free electron lasers. The equipment comprises a 1-1/2 cell radio-frequency electron gun with a metal photo-excited cathode producing up to 4.5 MeV electrons, two travelling wave, disc loaded, accelerating sections operating in the $2\pi/3$ mode and a beam transport and experimental area where studies utilizing the electron beam may be carried out. A quadrupled Nd:YAG laser is used to excite the photocathode and also to Q-switch a high power CO_2 laser which is therefore synchronized with the electron beam and can be used for the research program.

2 RF ELECTRON GUN SYSTEM

The rf gun[1] is shown schematically in Figure 1. It is a 1-1/2 cell, disc loaded, copper, structure operating in resonant π-mode with the photoexcited cathode situated on the end wall of the half cell. The coupling is designed to excite only the π-mode. The electron gun is followed by a low Energy Beam Transport System[2] (Figure 2) which allows for momentum selection and beam diagnostics equipment as well as providing a low energy (up to 4.5 MeV) Experimental Area. The system is also designed to "match" the beam from the electron gun to the accelerating sections with due regard given to space charge and rf field induced forces.

3 LINAC SYSTEMS

Figure 3 is a schematic diagram of the equipment layout for an acceleration experiment. A pulsed high power modulator with a pulse length of 5 μsec and a pulse repetition frequency of 6 Hz is used to power a 25 MW peak output power klystron which feeds the electron gun and the two accelerating sections. A phase locked oscillator operating at 81.6 Mhz provides the radio-frequency drive for both the Nd:YAG laser and, after suitable multiplication the 2.856 GHz drive to the klystron. A voltage controlled phase shifter and attenuator in the drive chain to the klystron allow changes in the amplitude and phase to the accelerating system. These parameters may be controlled by a feed forward system to maintain the desirable output beam parameters.[3]

A high energy beam transport system between the linac and the Experimental Area provides emittance and momentum selection capability for the individual experiments. A temperature controlled water-cooling system for the electron gun and accelerating sections maintains their temperature to 45$\pm$ 0.05°C. The laser transport line from the Nd:YAG laser to the electron gun is evacuated in order to maintain the desired phase stability between the lasers and the electron beam. All timing signals are derived from the primary 81.6 Mhz source. A commercial laser timing stabilizer is used to maintain laser stability to within $\pm$1 psec.

4 BEAM DIAGNOSTIC SYSTEMS

In the low energy beam transport system a momentum slit situated mid-way between two 90° bending magnets may be used to define and measure the beam momentum and momentum spread. The rear surfaces of the two slit jaws are coated with a phosphor scintillating material which can be viewed by a CCD camera system to give beam profile information. The slits are isolated from ground so that their collected charge can be monitored. A 2.856 GHz radiofrequency cavity operating in the TE_{102} mode, situated just ahead of the first 90° bend magnet may be used to deflect the beam vertically at the slit location and thus allows bunch time width measurements to be carried out. Beam profile monitors[4] utilizing phosphor screen viewed by CCD camera are used to record beam profiles in two locations thus enabling rms emittance measurements to be made. These monitors are placed just upstream of the first accelerating section and just before the low energy experimental area downstream of the second 90° bending dipole magnet which is not energized when low energy studies are in progress. Stripline beam position monitors are used to measure beam position and total charge in both the low and high energy beam transport lines. These can be calibrated against faraday cups placed at the end of the transport lines. The high energy beam transport line contains flags for viewing beam position, colimators to define small emittance beams, and a momentum defining slit, situated after the first 25° bending dipole, to allow for momentum measurements at high energy. Profile monitors are used for emittance measurements.

MASTER

5 CONTROL SYSTEMS

5.1 Adaptive Control

In general the macropulse to macropulse energy stability of the output beam is very good, however, various effects contribute to the energy spread of the beam within a macropulse, which may

*This work was performed under the auspices of the U.S. Department of Energy.

contain up to 200 microbunches. Beam loading effects would induce an energy charge during the pulse of up to 8% for the desired beam charge. Voltage ripple on the modulator delay line contributes ±0.6% to linac energy spread and also contributes phase errors. Our approach to this problem is to utilize a voltage controlled attenuator and phase shifter in the low level drive system vary the amplitude and phase of the klystron unsaturated output. These control elements are fed by arbitrary function generators controlled by a pc. The computer reads the cavity field and phase values which are then sampled by a digitizer and suitable corrections made to minimize amplitude and phase variations. Amplitude stability of ±0.2% and phase stability of ±0.6° have been achieved during a 3 μsec rf pulse after a few iterations.

5.2 Computer Control System.

The computer control system is based around a VAX 4000 series system. A Microvax II/GPX is used off-line for software development and testing. Control and monitoring of the facility's devices (magnet power supplies, beam position monitors, timing system, etc.) is through a Kinetic Systems Corporation CAMAC byte-serial highway driver connected to 4 CAMAC crates. From the CAMAC, communication to local devices is via industry-standard hardware interfaces and protocols such as EIA-RS-232 and IEEE-488. The facility is also equipped with an Ethernet interface and is connected to networks such as DECnet, HEPNET and Internet. The computer operates under version 5.4 of DEC's VMS operating system. Support for software development in both C and FORTRAN programming languages is provided. In addition, a commercial control system software package, marketed by Vista Control systems, Inc., is used to build window-based operator interfaces. All windowing operations are done using DECwindows, Digital's implementation of the X-windows standard. Operators interact with the control system through "point and click" pull-down menus which graphically display controls, overviews of the facility's status and alarm conditions. By employing the X-windows technology, these detailed graphic presentations will be available throughout the ATF. The Vista package also includes a database generator, various report writers and a library of program development routines.

6 LASER SYSTEMS

A Nd:YAG laser system is used for exciting the gun photocathode and switching the CO_2 laser. This system includes a Spectra-Physics CW oscillator (wavelength 1064 nm), mode locked to the 81.6 MHz rf reference source. A Lightwave Electronics series 1000 timing stabilizer is used to phase-lock the oscillator to the reference, reducing pulse-to-pulse timing jitter, or phase noise, of the laser to better than 1 ps. The oscillator pulse (about 80 ps long) is then chirped in a 200 m optical fiber and amplified bandwidth chops the chirped pulse to about 10 ps. A pulse train of up to 200 microbunches separated by 12.25 ns, may be switched by a Pockels cell. This output is frequency doubled and then transported about 30 m to the gun hutch where a second doubling takes place. At this point there is an energy of 100 μJ in a 6 ps pulse at the operating wavelength of 266 nm. This is sufficient to produce 1 nC of electron charge from the photocathode. Part of the output from the Nd:YAG at 1064 nm is used to switch a short, synchronized CO_2 laser pulse of 10 psec duration out of a 60 ns pulse from a CO_2 oscillator by using germanium plates which change from transmitters to reflectors when hit by 1064 nm light. A broadband, 4 atmosphere isotopic mix CO_2 amplifier then boosts the pulse up from 10 μJ to 500 mJ. The isotope mix $^{12}C^{16}O_2/^{12}C^{18}O_2/^{12}C^{16}O^{18}O$ at ratios of 1/1/2. A room temperature catalytic converter is used. Since the timing of the CO_2 pulse is determined by the Nd:YAG pulse, it is synchronized to the electron beam as well.

7 EXPERIMENTAL PROGRAM

7.1 General

One experimental beamline at the gun energy is available as a branch of the LEBT and three high-energy beamlines are available at the experimental hall, shown in Figure 5. The high energy beamlines are equipped with emittance selection as well as diagnostics for the longitudinal and transverse emittance, beam profile, energy, beam position and current. The CO_2 laser radiation may intercept two of the lines in order to perform experiments on laser acceleration or photon-electron scattering. The third line is dedicated to FEL experiments. The currently approved or proposed experiments at the ATF are:

- Visible FEL (BNL, Stony Brook, Rocketdyne)
- Grating Acceleration (BNL, LANL, Princeton, UCLA)
- Nonlinear-Compton Scattering (Princeton, BNL, LANL)
- Inverse Cerenkov Acceleration (STI, BNL, LANL)
- Study of Spiking Phenomena in FELs (Columbia)
- Room temperature, pulsed microwiggler (MIT)
- Inverse FEL (BNL, LANL, Yale, UCLA)
- Fast-Excitation Wiggler Development (BNL)
- Cerenkov and Metal Grating FELs (Dartmouth)
- Cyclotron Resonance Accelerator (MIT)
- Superconducting Cavity Wakefield Studies (Cornell)
- FEL and Electron Beam Optics and Diagnostics (Rocketdyne)

7.2 Early Experimental Program

The low energy (~3 MeV) beam is being used to characterize gratings for potential use as accelerating structures by measuring Smith-Purcell radiation produced when the electron beam is brought close to the grating. Shortly the 3 MeV beam will be used to measure the generation of far infrared radiation (10 μm to 1 cm) by sending it through various structures. The mechanisms responsible for generating this radiation include Smith-Purcell effect and Cerenkov radiation.

The first high energy (>40 MeV) experiment to be carried out will be Inverse Cerenkov using a radially polarized CO_2 laser beam and axicon focussing.[5] Preliminary scaling and modeling has shown the viability of this method for electron acceleration to high energies. For a 10 GW peak CO_2 laser power and a 50 MeV electron beam in a medium of low pressure hydrogen gas an acceleration of over 25 MeV in a 20 cm interaction length has been calculated. The CO_2 laser beam has been characterized and brought to the hydrogen cell at the peak power level of ~1 GW at a pulse length of ~100 psec. It is anticipated that reduction of the CO_2 laser pulse length to ~15 psec before final amplification should give sufficient peak power to carry out the experiment.

8 OPERATIONAL STATUS

All of the equipment for operation at 50 MeV into a beam stop in the beamline upstream of the Experimental Area has been installed and tested and beam tests at 50 MeV will commence in mid-August 1992 pending safety approvals. Low energy beam testing has been carried out with a copper cathode excited by the Nd:YAG laser and the results are summarized in Table I below.

Table I. BNL RF Gun Results to Date

	Design	Achieved
Energy, MeV	4.6	4.6
Repetition Rate, Hz	6	6
Electron pulse charge, nC	1.0	2.0
Electron pulse length, rms, ps	2.5	4.9
Peak Current, A	160	133
Energy spread, rms. %	0.3	0.4
Emittance ($\gamma\sigma_x\sigma_{x'}$), πm-rad	7×10^{-6}	4×10^{-6}
Beam Brightness, A/m^2	3×10^{12}	7×10^{12}

Acknowledgements

I would like to acknowledge the contributions of:
I. Ben-Zvi, R. Fernow, J. Fischer, A. Fisher, J. Gallardo, G. Ingold, H. Kirk, R. Palmer, Z. Parsa, I. Pogorelsky, J. Rogers, J. Sheehan, T. Srinivasan-Rao, T. Tsang, S. Ulc, A. van Steenbergen, W. Willis, M. Woodle and X.J. Wang of Brookhaven National Laboratory; I. Bigio, N. Kurnit and T. Shimada of Los Alamos National Laboratory; K. McDonald of Princeton University;; students working at the ATF and its experiments are K. Kusche, M. Babzien and I. Bottke (Stony Brook), and R. Stoner (MIT). The dedicated work of our technicians, C. Biscardi, W. Cahill, M. Montemagno, R. Harrington and J. Schill is also gratefully acknowledged.

References

1. K. Batchelor, H. Kirk, J. Sheehan, M. Woodle and K. McDonald, Proceedings of the 1988 European Particle Accelerator Conference, Rome, Italy, June 2-12, 1988.
2. X.J. Wang, H.G. Kirk, C. Pellegrini, K.T. Mcdonald and D.P. Russell, Proceedings of the 1989 IEEE Particle Accelerator Conference, March 20-23, 1989, p. 307.
3. I. Ben-Zvi, J. Xie and R. Zhang, Proceedings of the IEEE Particle Accelerator Conference, San Francisco, May 6-9, 1991, p. 1323.
4. D.P. Russell, K.T. McDonald and B. Miller, Proceedings of the 1989 Particle Accelerator Conference, March 20-23, 1989, p. 1510.
5. R.D. Romea and W.D. Kimura, Phys. Rev. D. 42, 1807 (1990).

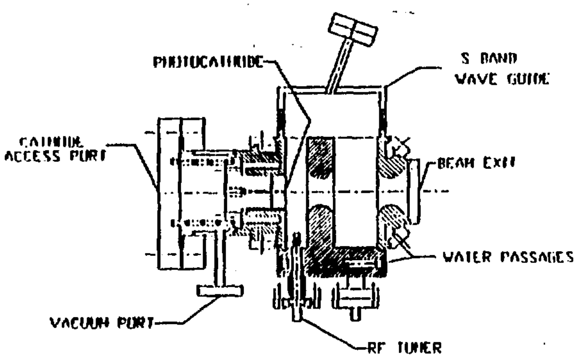

Figure 1. Radiofrequency Electron Gun.

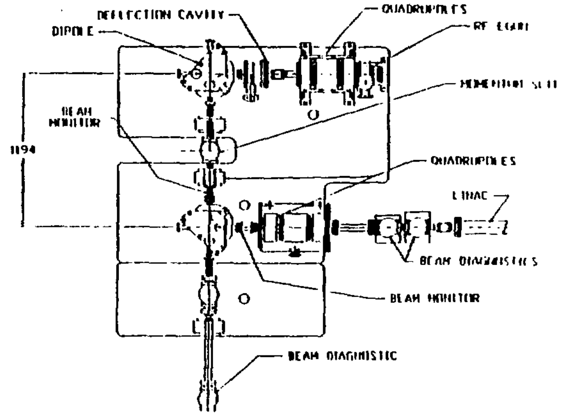

Figure 2. Low Energy Beam Transport System.

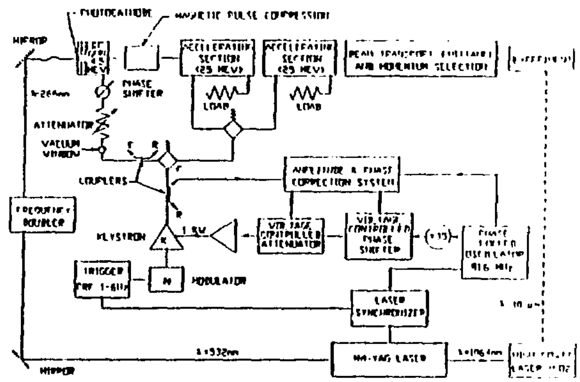

Figure 3. Equipment Schematic for an Acceleration Experiment.

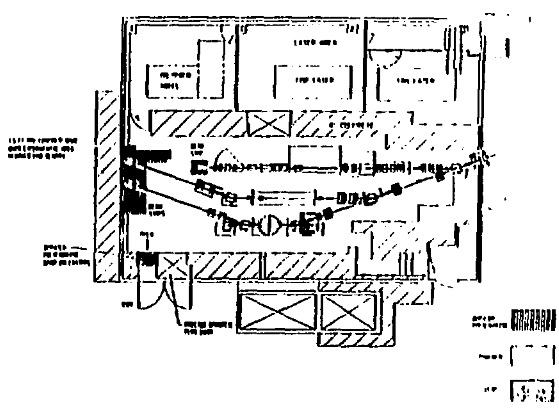

Figure 4. Experimental Equipment Area.

DISCLAIMER