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OPERATIONAL STATUS OF THE BROOKHAVEN NATIONAL LABORATORY ACCELERATOR TEST FACILITY*

K. Batchelor, I. Ben-Zvi, R.C. Fernow, J. Fischer, A.S. Fisher, J. Gallardo, Xie Jialin, H.G. Kirk, R.G. Malone, Z. Parsa, R. B. Palmer, T. Rao, J. Rogers, J. Sheehan, T.Y.F. Tsang, S. Ulc, A. vanSteenbergen, M. Woodle, R.S. Zhang
Brookhaven National Laboratory, Upton, NY

I. Bigio, N, Kurnit, T. Shimada
Los Alamos National Lab, Los Alamos, NM

K.T. McDonald, D.P. Russel
Princeton University, Princeton, NJ

Z.Y. Jiang
SUNY, Stony Brook, NY

C. Pellegrini, X.J. Wang
UCLA, Los Angeles, CA

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Initial design parameters and early operational results of a 50 MeV high brightness electron linear accelerator are described. The system utilizes a radio frequency electron gun operating at a frequency of 2.856 GHz and a nominal output energy of 4.5 MeV followed by two, 2π/3 mode, disc loaded, traveling wave accelerating sections. The gun cathode is photo excited with short (6 psec) laser pulses giving design peak currents of a few hundred amperes. The system will be utilized to carry out infra-red FEL studies and investigation of new high gradient accelerating structures.

Introduction

The Brookhaven Accelerator Test Facility[1] is a laser/linac complex comprising a radio-frequency electron gun utilizing a photo cathode excited by a 1 GW peak power Nd:YaG laser with a pulse length of about 6 psec, followed by two traveling wave accelerator sections operating in the 2π/3 mode. The electron beam of 50-100 MeV energy and 1 nc charge can be synchronized with a 6 psec pulse length, 100 GW, CO_2 laser to study the acceleration of electrons by a laser grating[2] or to provide a picosecond source of X-Rays via nonlinear Compton scattering.[3] In a multibunch mode it can be used to drive a free electron laser to give a photon source tunable over a wavelength range of 500-1000 nanometers.[4] Figure 1 is a block diagram of the linac and laser components as described in reference [1]. We report on progress with the installation and testing of the systems which make up the Accelerator Test Facility.

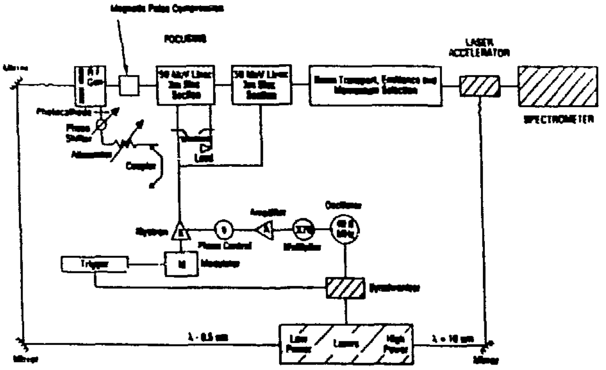

Fig. 1. Block Diagram of the Accelerator Test Facility

Electron Gun

The electron gun design parameters are given in Reference 5 and Figure 2 is a diagram of the gun as it was constructed. The gun has been operated with a Yttrium metal cathode excited by a 20 nsec pulse length excimer laser operating at a wavelength of 248 nm. The results obtained for this mode of operation are given in Table I. The emittance at 3.6 MeV as measured by the technique described in reference 6 was less than 10 π mm.mrad for a peak current of 0.6 A. The measured effective shunt impedance was 45.6 MΩ/m compared to a "SUPERFISH" calculated value of 57 MΩ/m. Subsequently the electron gun has been excited to higher power levels and a "dark current" beam of electrons of momentum equal to 4.2 MeV/c has been observed. This corresponds to a cathode electric field gradient of 90 MV/m as compared to the design value of 100 MV/m. The forward and reverse power signals from a waveguide directional coupler just in front of the electron gun are shown in Figure 3 and the measured and calculated "dark current" waveforms are shown in Figure 4.

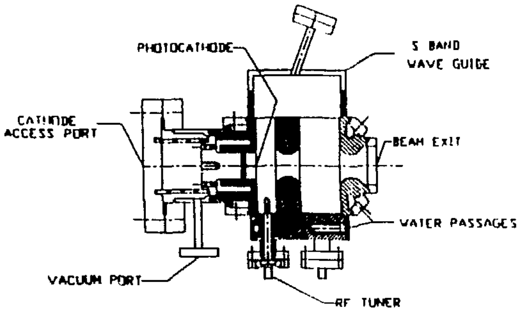

Fig. 2. Diagram of the Electron Gun

Table I
Brookhaven Accelerator Test Facility RF Gun Results

- 5 MW input RF power
- 600 μJ laser power at 248 nm
- Photo-ejected electrons accelerated to 3.6 MeV
- Measured Shunt Impedance = 45.6 MΩ/m
- dp/p = ± 0.5%
- I_{avg} = 8 mAmps
- I_{peak} = 0.6 Amps
- Initial quantum efficiency is 1.4 x 10^{-4}

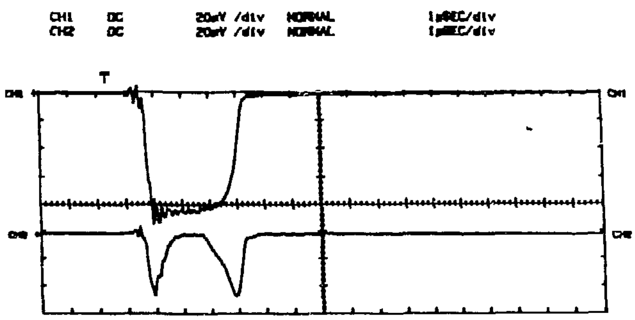

Fig. 3. Forward and Reverse Power Waveforms for the Electron Gun

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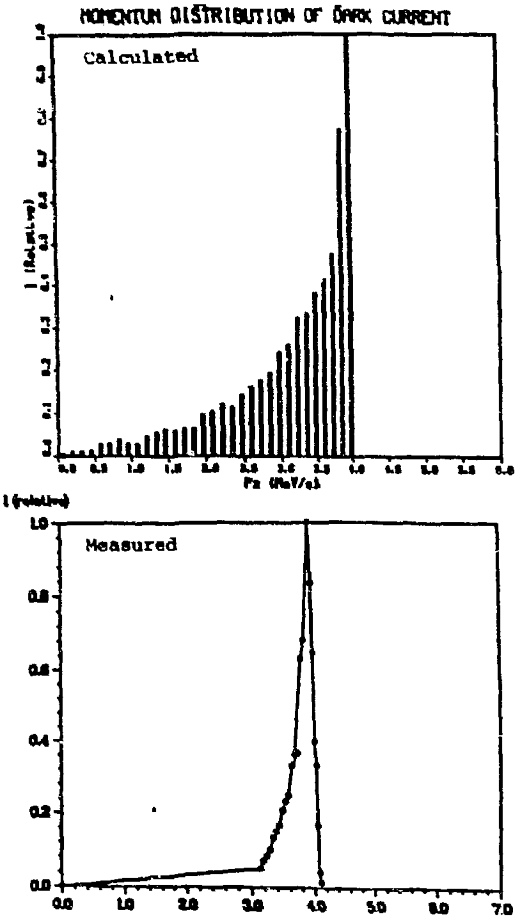

Fig. 4. Measured and Calculated Dark Current Waveforms

Low Energy Beam Transport System[7]

This system is designed to "match" the electron beam from the gun to the accelerating sections, to provide for possible magnetic pulse compression of the beam from the electron gun, and to allow diagnostic measurements to be made on the beam. This injection line is shown in Figure 5. The first element is a quadrupole triplet immediately after the electron gun which utilizes large aperture quadrupoles in order to minimize second and third order effects on the electron beam which emerges from the gun with a large divergence. This triplet provides a double waist between the two 90° dipole magnets where a momentum selection slit is located and momentum measurements can be made. A second triplet, after the two dipoles, is utilized to produce a double waist near the entrance to the first accelerating section. The two quadrupoles, one on each side of the momentum selection slit, work with the other magnetic elements to give an achromatic system. A radio-frequency deflecting cavity operating in the TE$_{102}$ mode at the 2856 MHz linac operating frequency may be used to deflect the beam vertically at the same time as the first 90° bending magnet spreads the beam horizontally. Thus, by turning off the second 90° bending magnet, utilizing appropriate quadrupole magnets to focus the beam, and using a beam profile monitor to measure the beam size in this straight ahead line we are able to determine the longitudinal parameters of the electron beam. In addition two beam profile monitors situated in tandem just prior to the first accelerating section will allow us to measure the transverse beam parameters at the injection energy. The system is made entirely of bakeable components and operates at a vacuum of about 10^{-9} Torr. Installation of this system is complete and beam measurements with the Nd.YaG laser will commence shortly.

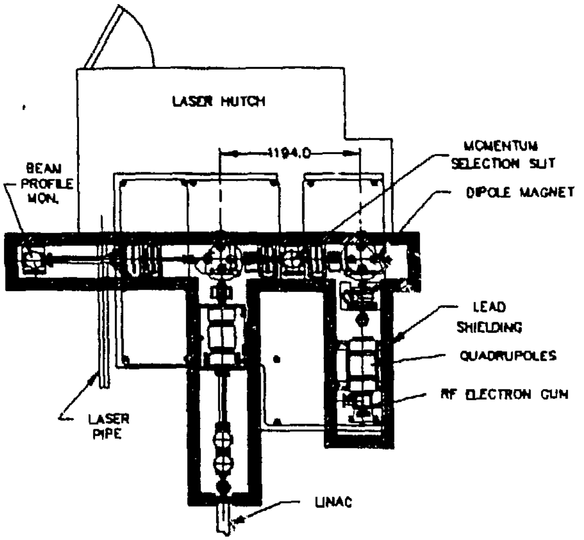

FIGURE 5
INJECTION LINE ARRANGEMENT

Linac Systems

The two accelerating sections are installed together with the associated radio-frequency system and vacuum and water systems. Since the r.f. pulse length (3.5 μsec) and pulse repetition frequency (6 Hz) are low there is very little average power dissipation in the accelerating structures and the water system serves mainly to stabilize the temperature to within ± 0.05° C. The radio-frequency system is shown schematically in Figure 6. A crystal oscillator operating at a frequency fo 40.8 MHz is used to drive both the linac, after multiplication by 70 to 2856 MHz, and the Nd.YaG laser. In this way, perfect synchronism between the linac rf and the laser optical pulses may be achieved providing that the system can be stabilized to within 1 psec (or one degree of phase at 2856 MHz). A voltage controlled attenuator and phase shifter is provided in the low level drive system to the single klystron used to drive the entire linac system, including the electron gun. Ultimately a feed forward system which will utilize measurements on a beam pulse (or r.f. pulse) to correct the succeeding pulse will be implemented in order to improve the beam quality when operating in a multibunch mode for free electron laser studies. All of these systems have been installed and operated up to a klystron output power of 25 MW.

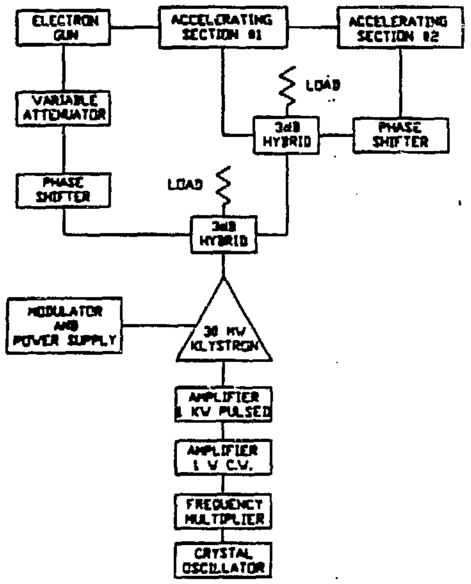

FIGURE 6 R.F. POWER SYSTEM LAYOUT WITH ONE KLYSTRON

High Energy Beam Transport Systems

The various elements of this transport system are designed to provide beam waists at appropriate places for the three experimental beam lines, to allow for momentum analysis and transverse emittance measurements on the beam, and to provide the best beam parameters possible at the various experiments. The designs have been completed utilizing a version of TRANSPORT and all of the magnetic components and power supplies have been ordered. Concrete support plinths for the magnetic elements are in place as are the support stands. The vacuum system and beam pipe design is complete and manufacture is in progress.

Beam Diagnostics

Up to the present time a faraday cup has been used to measure the charge of the electron beam at 4.2 MeV/c. A four plate strip line monitor has been designed to allow for position and beam current measurements in both the injection line and the high energy beam transport lines. First tests with beam will commence shortly. Beam profile measurements have been made on the beam from the electron gun utilizing two phosphor screens viewed by a CCD camera as described in reference [6]. The video images are digitized and stored by a frame grabber before being analyzed by an IBM PC-AT to extract the emittance. The system is capable of measuring a transverse geometric emittance of about 1 mm-mrad. Emittance measurements utilizing a "pepper-pot" technique are also planned.

Control System

The control system for the Accelerator Test Facility is built around a Micro VAX II/GPX computer manufactured by Digital Equipment Corporation (DEC). The system is configured with 13 Mbytes of main memory, 720 Mbytes of on-line disk storage, a 1024 pixel by 864 pixel, 8-plane high-resolution color monitor with mouse and an Ethernet interface. Control and monitoring of the facility's devices (magnet power supplies, beam position monitors, etc.) is through a standard CAMAG byte-serial highway connected to 3 CAMAC crates. Drivers have been written to provide communications via several industry standard protocols such as RS-232 and IEEE-488. The facility is also connected to the BNL site-wide DECnet network, the HEPNET high energy physics network as well as the Internet. These links provide local and international communications for both ATF staff and visitors.

The computer operates under version 5.2 of DEC's VMS operating system. Support for software development in both the C and FORTRAN programming languages is provided. In addition, a commercial software package, marketed by Vista Control Systems, Inc., is used to build window-based operator interfaces under DEC's VAX Workstation Software, VWS. Operators interact with the control system through "point and click" pull-down menus. These windows provide users with controls, an overview of the facilities status, and alarm conditions. This package also includes a database generator, various report writers, and program management utilities.

To date, all the above described hardware and systems software have been installed and tested. Complete monitoring and control of the front end magnet power supplies has been demonstrated. Work is underway to provide real-time monitoring of beam position, control of trim magnet power supplies and status of the facility safety interlock systems. Plans call for the conversion of the entire windowing system to the X-Windows standard by the end of summer 1990. The windowing scheme will then be available to both operations personnel and experimenters at various locations throughout the facility through X-Windows terminal equipment connected to the local Ethernet.

Laser Systems

The excimer laser used in earlier ATF measurments has been replaced by a frequency quadrupled Nd:YAG system. The old system excited the photocathode of the electron gun at 248 nm with a single 20 ns pulse (repeating at ATF's 6 Hz rate), thus providing continuous illumination over 60 rf periods. The new system, operating at 266 nm, will produce ≈ 6 ps pulses, a time corresponding to only 6° of the rf cycle.

A CW Nd:YAG oscillator, mode locked to ATF's 40.8 MHz rf reference, produces a train of 100 ps pulses with 12.25 ns spacing. A feedback system will reduce jitter in the synchronization of these pulses with the gun's rf to 1 ps. Fiber chirping, compression, and amplification result in ≈ 12 ps pulses of 12 mJ at 1064 nm. The output is frequency doubled to 532 nm and sent to the gun end of the linac. After a second doubling there, to 266 nm, the pulses are 6 ps long and have 100 μJ, an energy sufficient to produce 1 nC from the cathode. Initial experiments will be performed with the amplifier in a single pulse configuration, designed for experiments in which one electron bunch interacts with the single, 6 ps output pulse of the CO_2 laser. A second arrangement will produce an amplified train of up to 200 pulses, in order to provide multiple electron bunches for the free-electron laser.

ATF's laser acceleration and nonlinear Compton scattering experiments require a highpower CO_2 laser with a 6 ps pulse duration to match that of the electron bunches. Such a laser has been built by Los Alamos, and is now being completed at ATF. Germanium plates switch from being transmitters to reflectors of CO_2 radiation when they are hit by 1064 nm light from the Nd:YAG laser. In this manner, a 6 ps pulse can be switched from the output of a 60 ns CO_2 oscillator, at a time synchronized with the photocathode. A broadband CO_2 amplifier (4 atm, with an isotopic mixture) will then boost the pulse to between 50 and 500 mJ.

Acknowledgements

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