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OPERATION OF THE BROOKHAVEN NATIONAL LABORATORY ACCELERATOR TEST FACILITY*

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Abstract

Early operation of the 50 MeV high brightness electron linac of the Accelerator Test Facility is described along with experimental data. This facility is designed to study new linear acceleration techniques and new radiation sources based on linacs in combination with free electron lasers. The accelerator utilizes a photo-excited, metal cathode, radio frequency electron gun followed by two travelling wave accelerating sections and an Experimental Hall for the study program.

Introduction

The Accelerator Test Facility at Brookhaven National Laboratory is a laser/linac complex designed to produce high brightness beams for accelerator physics users to study new linear acceleration techniques. It also serves as a tool to study advanced radiation sources based on free electron laser technology. The equipment comprises a 1-1/2 cell radiofrequency electron gun with a metal, photo-excited, cathode, which produces electrons with energies up to 4.5 MeV. This is followed by two, $2\pi/3$ mode travelling wave acceleration sections and, after a beam transport line for suitable emittance selection and beam monitoring, an experimental area with three separate beam lines for accelerator studies.

RF Electron Gun System

The rf gun [1] is shown schematically in Fig. 1. It is a 1-1/2 cell, disc loaded, copper structure operating in resonant π-mode with the metal photoexcited cathode situated on the end wall of the first half cell. The waveguide feed is designed to couple only the π-mode. The gun is followed by a Low Energy Beam Transport System [2], Fig. 2, which allows for momentum recombination and pulse compression of the electron beam. There is also a momentum slit for energy selection and a Low Energy Experimental Region allowing for tests with up to 4.5 MeV beams. 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.

Linac Systems

The equipment layout for a typical advanced acceleration experiment is shown schematically in Fig. 3. A pulsed high power modulator with a pulse length of

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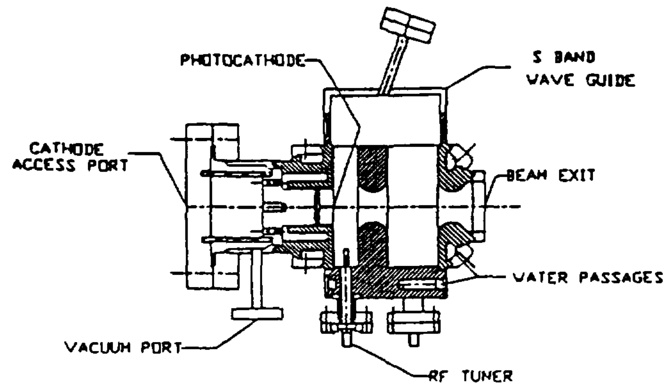

Fig. 1. The Brookhaven 1-1/2 cell gun.

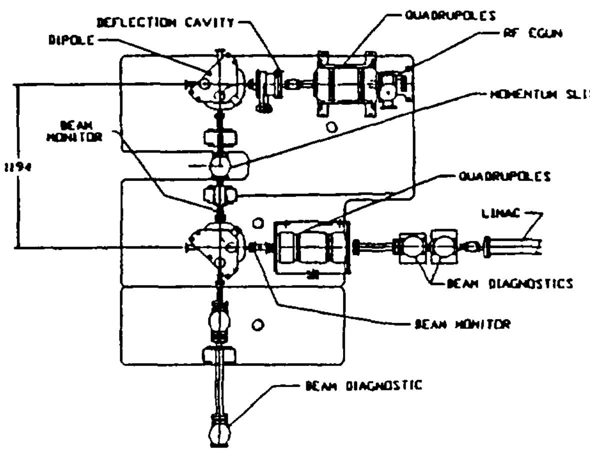

Fig. 2. Low Energy Beam Transport System.

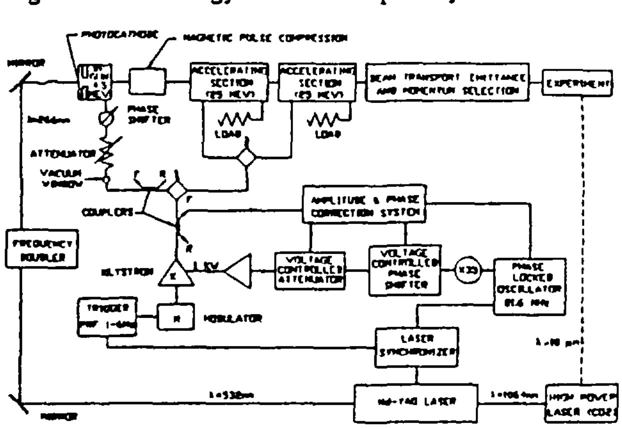

Fig. 3. Schematic of Equipment Layout for an Acceleration Experiment.

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 radiofrequency 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 amplitude and phase to the entire accelerating system. These parameters may be controlled by a feed forward system to maintain the desired output beam parameters [3].

A high energy beam transport system between the linac and the experimental area provides emittance and momentum selection for the individual experiments. Temperature controlled water-cooling systems for the gun and acceleration sections maintain their temperatures to within ±0.05°C of design values. The laser transport line from the Nd:YAG laser to the electron gun is evacuated in order to maintain the desired stability between the laser and the electron beam. All timing signals are derived from the primary 81.6 MHz source and a commercial laser timing stabilizer is used to maintain laser stability to within ±1 psec.

Beam Diagnostic Systems

For the low energy beams the momentum slit between the two 90° dipole bending magnets may be used for momentum analysis and selection. The entry surfaces of the two slit jaws are coated with a fluorescent material which can be viewed by a CCD camera system to give beam provide information. The slits are isolated from ground so that collected charge may be measured. A 2.856 GHz radiofrequency cavity operating in the TE_{102} mode, situated just ahead of the first dipole magnet may be used to deflect the beam vertically at the slit allowing for bunch time width measurement. Beam profile monitors [4] utilizing CCD cameras are used to record beam profiles in two locations and hence determine the rms emittance. 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 also contains flags for viewing beam size and position, colimators to define small emittance beams, and profile monitors for emittance measurement. A momentum defining slit situated after the first 25° bending dipole magnet allows for momentum measurements at high energy.

Control Systems

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 contain up to 200 microbunches. For the desired beam charge an energy change of 8% would be induced during the macropulse. Voltage ripple on the modulator delay line contributes ±0.6% to energy spread and also contributes phase errors. Our approach to this is to utilize a voltage controlled attenuator and phase shifter in the low level drive system to vary the amplitude and phase of the klystron's unsaturated output. These control elements are fed by arbitrary function generators controlled by a personal computer. 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 macropulse after a few iterations.

Computer Control

The computer control system is based on a VAX 4000 series system. A Microvax II/GPX is used off-line for software development and testing. Control and monitoring of the facility devices (magnet power supplies, beam position and size monitors, timing system, etc.) is through a Kinetic System Corporation CAMAC byte-serial highway driver connected to four 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. Operators interact with the control system through "point and click" pull down menu's which graphically display controls and overviews of the facilities status and alarm conditions. By employing X-windows technology, these detailed graphic presentations are available throughout the ATF complex. The Vista package also includes a database generator, various report writers and a library of program development routines.

Laser Systems

A Nd:YAG laser system is used for exciting the gun photo-cathode and also for Q-switching a CO_2 laser. The system includes a Spectra-Physics CW oscillator (wavelength 1064 nm), mode locked to the 81.6 MHz rf drive system source. A Lightwave Electronics series 1000 timing stabilizer is used to phase-lock the oscillator to the reference, reducing pulse to pulse jitter to better than 1 ps. The oscillator pulse (about 80 ps long) is then chirped in a 200 m optical fiber and amplified. Bandwidth limitations in the amplifier chop the chirped pulse to about 10 ps. A pulse chain of up to 200 microbunches separated by 12.25 nS may be switched by a Pockel's cell. The output pulse is then frequency doubled and 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 copper photocathode. Part of the output from the Nd:YAG at 1064 nm wavelength is used to switch a short, synchronized, CO_2 laser pulse of 10 ps pulse 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. A room temperature catalytic converter is used. Since the timing of the CO_2 pulse and the electron beam is determined by the Nd:YAG pulse they may be exactly synchronous at the experiment.

Operational Status

All of the accelerator equipment for operation at 50 MeV into a beam stop in the beam line upstream of the Experimental area has been installed and tested and beam studies are in progress. Low energy beam testing has been carried out with a photo-excited copper cathode and the results are summarized in Table 1 below. A typical emittance plot is show in Fig. 4.

Table 1
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	$7x10^{-6}$	$4x10^{-6}$
Beam Brightness, A/m^2	$3x10^{12}$	$7x10^{12}$
UV Energy, μJ	50	300
IR Pulse Length (FWHM), ps	12	20

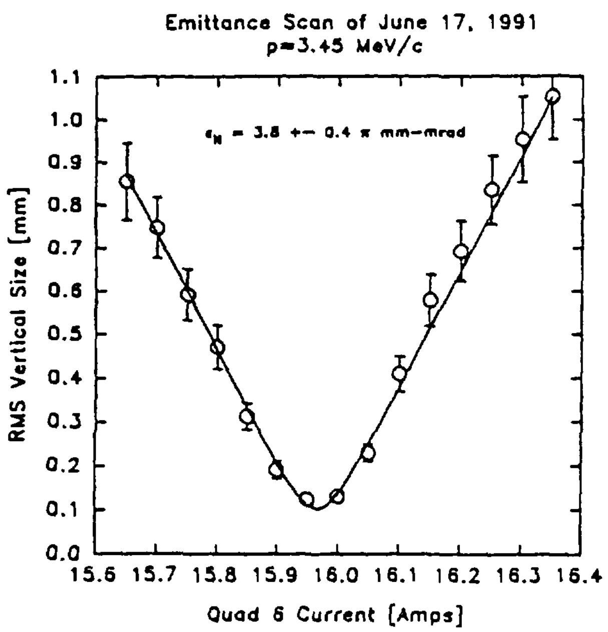

Fig. 4. The vertical projections of the electron beam on a profile monitor as a function of quadrupole current.

Experimental Program

One experimental beam line at the gun energy is available for experiments and three high energy beam lines are set up in the Experimental Hall for high energy tests. The CO_2 laser radiation may intercept two of these lines in order to perform experiments on laser acceleration, photo-electron scattering or as a seed laser for an FEL based harmonic generation experiment. The third beam line is dedicated to FEL experiments not requiring the CO_2 laser.

The low energy beam is being used to characterize gratings for potential use as accelerating structures by measurement of Smith-Purcell radiation produced when the electron beam is brought close to the grating. Also the 3 to 4.5 MeV beam is being used to measure far infrared radiation (10 μm to 1 cm) by sending it through various structures. The mechanisms responsible for generating this radiation include Smith-Purcell and Cerenkov radiation.

The first high energy (>40 MeV) experiment to be carried out will be the 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 50 MeV electron beam in a medium of low pressure hydrogen gas an acceleration of 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 the pulse length of ~100 ps. It is expected that a reduction of CO_2 laser pulse length by slicing to ~15 ps before final amplification should give sufficient peak power to carry out the experiment.

Acknowledgement

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