OPERATIONAL EXPERIENCE ON THE BROOKHAVEN NATIONAL LABORATORY ACCELERATOR TEST FACILITY*

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Abstract

Brookhaven National Laboratory Accelerator Test Facility is a laser-electron linear accelerator complex designed to provide high brightness beams for testing of advanced acceleration concepts and high power pulsed photon sources. Results of electron beam parameters attained during the commissioning of the nominally 45 MeV energy machine are presented.

1. INTRODUCTION

The Accelerator Test Facility [1] (ATF) is operating as a user facility for accelerator and beam physicists to carry out research on new acceleration techniques or advanced optical sources. It is equipped with a laser-photo-cathode electron gun, an electron linac initially at a nominal 45 MeV energy, and a high power short pulse CO_2 laser synchronized with the linac rf system. This laser may be used to energize various devices which may accelerate the 45 MeV electron beam. This paper will present operating results of the electron gun together with some early experimental results attained with the low energy (3 to 5 MeV) and high energy (up to 45 MeV) electron beams.

2. ELECTRON GUN OPERATION

2.1. Low Energy Experimental Layout

The electron gun has been operated for both the study of metal photo-cathodes and for the experimental program. The low energy transport system is shown schematically in Fig. 1. The ATF one-and-half cell microwave gun was powered by a 2856 MHz, SLAC XK-5 klystron and the magnesium cathode was mounted at the back wall of the half cell using a choke joint. A laser pulse struck the cathode at normal incidence through the first 90° dipole magnet. The photoelectron beam generated was either injected to the linac through a double bend electron beam transport line, or to a low energy experimental station (named the z-line) using just the first dipole magnet. The electron beam was accelerated at energies up to 3.5 MeV in the microwave gun and then focused by a quadrupole triplet. It was then bent by a 90° dipole to a momentum analysis slit which has electrically isolated jaws and whose front surface is coated with phosphor. Therefore it can be used for charge measurements and as a beam profile monitor. The quadrupole doublet in the z-line was used to produce a suitable beam at the downstream beam profile monitor for emittance measurement. A stripline position monitor was installed ahead of the first dipole magnet to measure the electron beam intensity and position. The beam line also includes a 2856 MHz microwave deflection cavity which was used for the electron beam bunch length measurement.

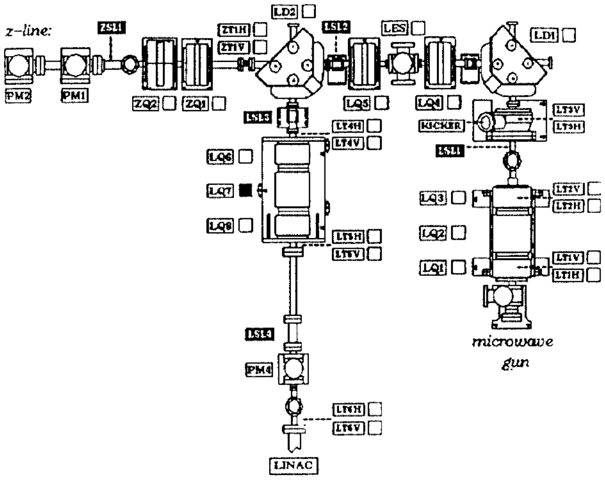

Fig. 1. The ATF Injection System.

2.2. Laser Systems Layout

The laser used to excite the photo-cathode utilizes a CW mode- locked Nd:YAG oscillator, phase locked to the 81.6 MHz master oscillator of the RF system. The Nd:YAG output is frequency chirped in a 200 m long single mode fiber. A single pulse, or a pulse train, selected by a Pockel's cell, is amplified in a Nd:YAG amplifier chain. The 1.06 μm wavelength amplified pulse is frequency doubled to 532 nm wavelength in a KDP crystal, then doubled again to a wavelength of 266 nm or ultraviolet (UV) light in a BBO crystal. For single pulse operation, up to 200 μJ of laser energy is available for photoelectron production. The optical arrangement near the gun cathode is shown schematically in Fig. 2. It is possible to change laser spot diameter and position at the cathode and the laser energy. For experiments with a magnesium, Mg, cathode a special optic was used to split off 90% of the laser energy for on-line monitoring, only 10% being required for excitation of the Mg cathode.

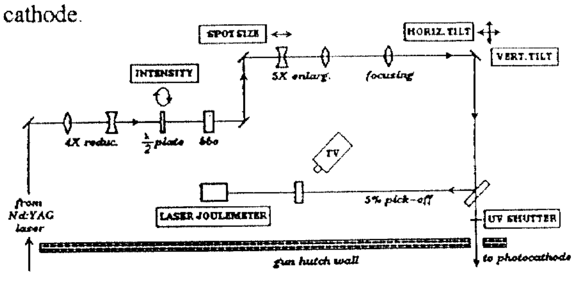

Fig. 2. Optical system to provide a laser spot on the cathode.

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3. EXPERIMENTAL AREA ARRANGEMENT

3.1. *General Layout*

A general layout of the Experimental Area is shown in Fig. 3. After acceleration to an energy of 45 MeV in two traveling wave, $2\pi/3$ mode accelerating sections the electron beam was transported through a series of quadrupole focusing magnets and a single 20 degree dipole magnet to the Experimental Area where it was bent by a second 20 degree dipole to any one of three experimental stations. At appropriate locations along these beam transport lines there are beam profile monitors utilizing CCD cameras to measure the beam size and stripline monitors to measure the beam position and intensity. A momentum slit situated just upstream of the Experimental Area was used for momentum analysis and, or selection and a Faraday cup situated in a straight ahead line after the first 20° bending dipole was used for intensity measurements and to calibrate the stripline monitors.

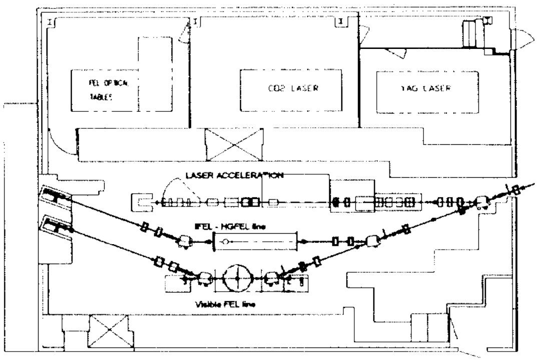

Fig. 3. ATF Experimental Area Layout.

3.2. *Laser Arrangement for the Experimental Area*

Part of the output from the Nd:YAG laser at the wavelength of 1064 nm was used to slice a short synchronized CO_2 laser pulse of 10 to 300 ps duration out of a 100 ns pulse from a CO_2 oscillator by using germanium plates that change from transmitters to reflectors when hit by 1064 nm light.

A broadband, 3 atmosphere CO_2 amplifier was used to amplify the sliced pulse to produce several hundred mJ in 50 to 300 psec pulses which were synchronized to the electron beam at the experiment by suitable adjustment of the length of the laser transport to the experiment.

3.3. *Momentum Analysis of the Electron Beam*

Each of the experimental beam lines is provided with a bending magnet for momentum analysis and a Faraday cup and striplines for charge and beam position measurements. For the line used for laser acceleration experiments the analysis system is also used to monitor the accelerated beam. A detailed description of this analysis system is given in Ref. [2] .

4. EXPERIMENTAL RESULTS

4.1. *Magnesium Photo-cathode Measurements [3]*

For experiments on the Mg cathode the total charge was normally kept below 100 pC in order to avoid space charge effects. For a total electron charge of 80 pC, a laser spot rms radius of 0.2 mm and laser pulse length of 10.6 pSec FWHM (as measured with a Streak Camera) we obtained a measured rms beam bunch length of 4.7 psec or 11 psec FWHM. The measured normalized emittance was 2.5 mm-mrad which is in agreement with the calculated value. We obtained a maximum quantum efficiency of 5×10^{-4} at a cathode field of 70 MV/m. At higher charge levels, up to 3 nC measured at the momentum slit, we measured a quantum efficiency of 3×10^{-4}. The Mg cathode was operated for >5000 hours without any degradation in performance. The electron gun operated at a vacuum of about 10^{-7} Torr.

4.2. *Smith-Purcell Grating Experiments at up to 5 MeV*

Walsh [4] et al. have carried out experiments on the z-line at the ATF using a 2.8 MeV electron beam over gratings with periods of 1,2,4 and 10 mm and blaze angles of 5, 20 and 30 degrees. Detailed studies of the coupling strengths for the beam-gratings interaction were made and spectral features predicted by the Van der Berg models for Smith-Purcell emissions were verified. There was evidence of relativistic enhancement at forward angles. Figure 4 shows the experimental results of these studies of far infra-red radiation.

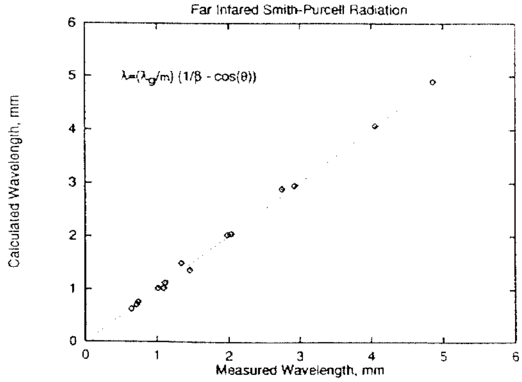

Fig. 4. Smith-Purcell experimental results.

4.3. *Inverse Cerenkov Acceleration at 40 MeV [5]*

A 0.7 GW peak power radially-polarized CO_2 laser beam at a wavelength of 10.6 µm and a pulse length of 220 ps was focused by an axicon into a pressurized hydrogen cell whereby the hydrogen gas is used to slow the light wave to match the electron beam over an interactive length of 12 cm. Acceleration of >3.7 MeV was achieved by use of the Inverse Cerenkov effect. The observed energy gain and the dependence on gas pressure agree with model predictions. Figure 5 is a schematic showing the experimental chamber, Figure 6(a) the spectrum with no laser present and Figure 6(b) with 0.7 GW peak laser power into the cell, each with 2.2 atm H_2 at 16.7° C in the cell. The total charge accelerated in a single electron bunch was ≈0.1 nC. and the electron bunch length (FWHM) was ≈10 ps. The intrinsic energy spread was ≈±0.5 MeV and the estimated normalized emittance was between 5 and 10 π mm-mrad.

4.4. *Pulsed Electromagnet Microwiggler at 40 MeV [6]*

A pulsed electromagnetic microwiggler developed by R. Stoner, S.C. Chen and G. Bekefi at MIT was installed in Experimental Line #3 (Visible FEL Line) at the ATF in order to

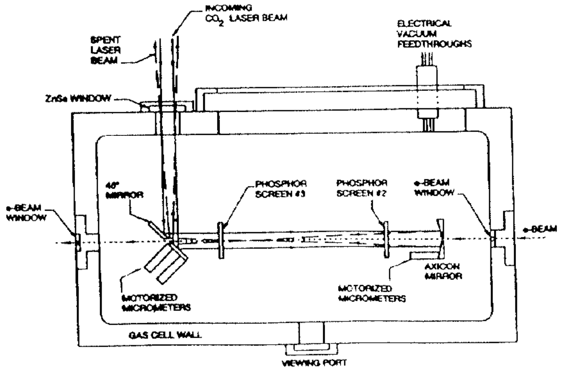

Fig. 5. Inverse Cerenkov Experimental Chamber.

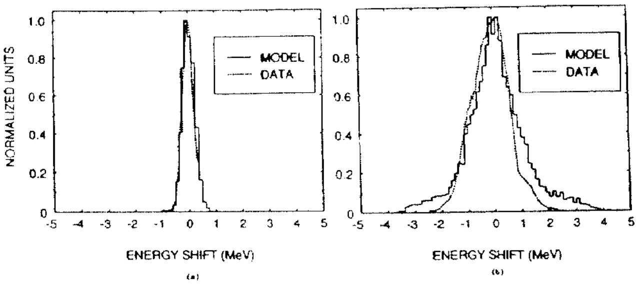

Figure 6. Energy spectra from the Inverse Cerenkov Experiment.

measure spontaneous emission spectra at energies around 40 MeV. The wiggler has a period of 8.8 mm and a gap of 4.2 mm for 70 periods. It was operated at a peak magnetic field of ≈4 KG. The spontaneous emission spectra measured at mean electron energies of 40.32 MeV and 40.86 are shown in Fig. 7 and are consistent with the theoretical predictions.

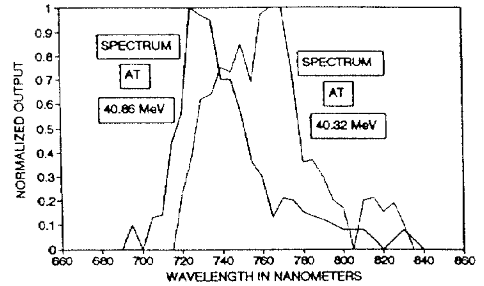

Fig. 7. Spontaneous Emission Spectra for the MIT Wiggler.

4.5. Tests on the Inverse Free Electron Laser Wiggler and Optical Waveguide [5]

The Vanadium Permandur (VAP) ferromagnetic laminated wiggler for the proposed IFEL was tested on the Experimental Line #3. The wiggler was assembled in a 1 cm constant period length configuration and a gap of 4 mm. It was complemented with the circular sapphire dielectric waveguide and a 42.5 MeV electron beam was successfully transmitted through the 2.8 mm ID guide. The spontaneous radiation spectrum was observed as predicted by theory (see Figure 8).

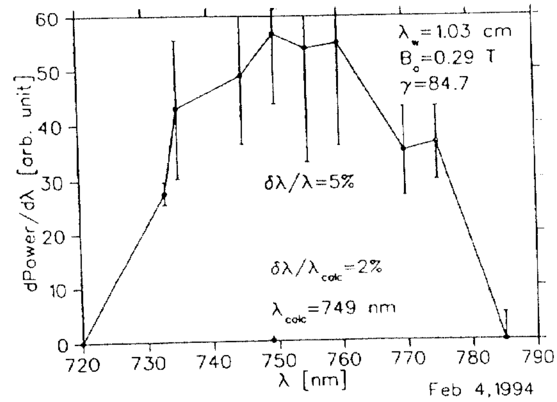

Fig. 8. Spontaneous Radiation Spectrum for the IFEL Wiggler.

5. CONCLUSIONS

A number of experiments at nominally 4 MeV and 45 MeV energy have been successfully carried out at the Accelerator Test Facility. Synchronization of the CO_2 laser beam with the electron beam has been achieved and the use of a metal photo-cathode in conjunction with a Nd:YAG laser was also demonstrated.

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