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THE BROOKHAVEN ACCELERATOR TEST FACILITY

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Abstract

The Brookhaven Accelerator Test Facility (ATF) will consist of a 50-100 MeV/c electron linac and a 100 GW CO_2 laser system. A high brightness RF-gun operating at 2856 MHz is to be used as the injector into the linac. The RF-gun contains a Nd:Yag-laser-driven photocathode capable of producing a stream of six ps electron pulses separated by 12.5 ns. The maximum charge in a micropulse will be one nano-Coulomb. The CO_2 laser pulse length will be a few picoseconds and will be synchronized with the electron pulse. The first experimental beam is expected in Fall 89. The design electron beam parameters are given and possible initial experiments are discussed.

I. Introduction

The Brookhaven Accelerator Test Facility will initially consist of a 50 MeV electron beam with a six ps bunch length and a carbon dioxide laser capable of a peak power of 100 GW and two to five ps pulses. In the second phase of the project, we plan to upgrade the electron beam energy to approximately 100 MeV. The principal feature of the facility will be the ability to synchronize the electron and laser pulses, thus opening the door to a wide variety of interesting experiments including laser acceleration of particles and generation of coherent radiation.

The accelerator consists of two S-band linear accelerating sections. The injection of the six ps electrons into the accelerating sections will be initiated by an Nd:Yag laser which will illuminate a photocathode embedded in an RF-gun designed and built at Brookhaven.[1] The Nd:Yag laser will also be used to trigger the CO_2 laser pulse, thus permitting the sychronization of the electron and CO_2 laser beams.

II. Linear Accelerator

The linac consists of two SLAC type three-meter acceleration sections which have been fabricated at the Institute for High Energy Physics in Beijing, China. Initially, the power for the linac sections and the RF-gun will be supplied by a single 20 MW klystron which has been provided to us by SLAC. We have assembled our modulator at BNL with several important components also provided to us by SLAC.

At a later stage the facility will be upgraded to 100 MeV by adding a second klystron and building a second modulator at BNL. The system is capable of running at a repetition rate of six Hz. Careful attention is being given to the mechanical supports and the cooling system of the linac in order to insure that the time stability of the system is on the order of one ps. The main characteristics of the initial phase of the linac operation are given in Table 1.

III. Injection System

The injection of the electron pulses into the accelerating sections will be accomplished by means of an RF-gun followed by a 180^0 double bend (see Fig. 1) which will allow both a magnetic compression of the electron bunches and convenient access to the photocathode by the Nd:Yag laser beam.

The RF-gun is based on a design in which a photocathode is incorporated in the end wall of an RF-cavity.[2] In our design, the RF-cavity consists of a disc-loaded, $1\frac{1}{2}$ cell cavity which is filled with a π-mode 2.856 GHz standing-wave. The disc walls are two cm thick with a radius of curvature of one cm. This was found to be a reasonable approximation of the ideal cell wall shape neccessary to linearize the radial electric and magnetic forces as the electron beam passes through the apertures. We require that the RF-induced emittance growth be minimized as the electron bunch traverses the gun. Power is coupled to the gun by directly attaching a waveguide to the sidewall of the gun cavity. Since the circulating magnetic lines of the TE_{10} mode within the waveguide match the sense of the circulating magnetic field lines of the π-mode within the gun, a strong coupling to the π-mode is effected while the zero-mode is suppressed. The parameters of the RF-gun are given in Table 2. Details of the design of the gun have been previously published.[1]

We anticipate operating the gun in two distinct modes: (1) a high-intensity mode, and (2) a low-intensity mode. A study of beam properties and techniques for producing a low-intensity and low-emittance beam similar to our planned beam has been previously published.[3]

In order to maximize the brightness of the emitted electron beam in the high-intensity mode, we have adopted a strategy which places a strong electric field near the photocathode in order to quickly accelerate the electrons before the self-fields can result in emittance blow-up. For the BNL RF-gun, the peak axial electric fields are 100 MV/m and the space-charge effects are minimal after the electron bunch is beyond one cm from the photocathode. Extensive modeling[4] has been done in order to understand the beam dynamics of our RF-gun.

In the early stages of our RF-gun program, a thermionic cathode will be used to permit us to study the properties of the RF-gun immediately. In Table 3 we list the expected beam parameters from all modes of RF-gun operation including that with the thermionic cathode.

IV. Laser and Photocathode

An important design criterion for our RF-gun is the ability to replace conveniently the photocathode surface within the RF-cavity. The cathode material will be deposited on a removable 1.2 cm radius plug in the end face of the gun. An RF-choke joint is used to avoid direct electrical contact between the plug and the cavity walls which could cause sparking during the operation of the gun with electric fields of up to 100 MV/m.

The future demands of our experimental program require the photocathode to have a picosecond response time, good quantum efficiency, good mechanical stability, and low intrinsic emittance.[5] In the initial operation we will use a yttrium cathode utilizing its robust mechanical properties. The work function of yttrium is about 3.1 eV and it will be illuminated by either a frequency-quadrupled (4.65 eV) or -tripled (3.5 eV) Nd:Yag laser depending on the requirements of the experiments. In a later phase of the program, a Cs_3Sb cathode may also be used.

The laser-driven photocathode will allow great flexibility for running a wide variety of experiments. The electron pulse length can be conveniently formed by shaping the pulse from the Nd:Yag laser. The intensity of the beam will be varied by changing the radius of the laser spot size on the photocathode surface. A high-intensity beam of one nano-Coulomb per pulse can be formed by illuminating the cathode surface with a six mm spot size laser beam, while a low-intensity,low-emittance beam will ensue when the spot size is reduced to as little as 40 μm.

The Nd:Yag laser will be driven at 40.8 MHz by stepping down the 2856 MHz RF drive for the linac and RF-gun by a factor of 70. This permits synchronization of the laser pulse on the photocathode with the oscillating fields within the RF-gun. Further, the Nd:Yag laser pulse will be shaped and used to initiate the CO_2 laser pulse which will then be amplified to peak powers of 100 GW. This will allow a wide class of experiments based on the coincidence of the electron beam with the CO_2 laser beam.

V. Experiments

Several experiments are being discussed which can exploit the unique features of the BNL ATF. The initial experiment will study the principles of laser acceleration and focusing of particles by illuminating various open structures with the 10 μm wavelength light of a CO_2 laser. Such a program requires the developement of techniques to produce micro-structures with dimensions equal to the characteristic wavelength of the laser and thus support electromagnetic fields. These techniques are currently being developed at Brookhaven National Laboratory.[6]

Another approach to the acceleration of particles is being considered using the inverse free electron laser principle.[7] Using the CO_2 laser and a 60 cm long undulator it would be possible to double the electron beam energy to 100 MeV.

A second class of experiments which utilizes the high intensity electron beam would be Free Electron Laser experiments. With the 50 MeV beam and a conventional undulator one can produce an Infrared FEL. Studies are also under way to consider ways for building a soft x-ray FEL.[8]

Other experiments being discussed include the study of switched-power devices for the acceleration of particles, the nonlinear dynamics of electrons in an intense electromagnetic field,[9] and the production pico-second light from the backward Compton scattering of laser light off an electron pulse.

Acknowledgements

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Figure Captions

Fig. 1: The Brookhaven ATF injection line from the RF-gun source to the accelerating sections.

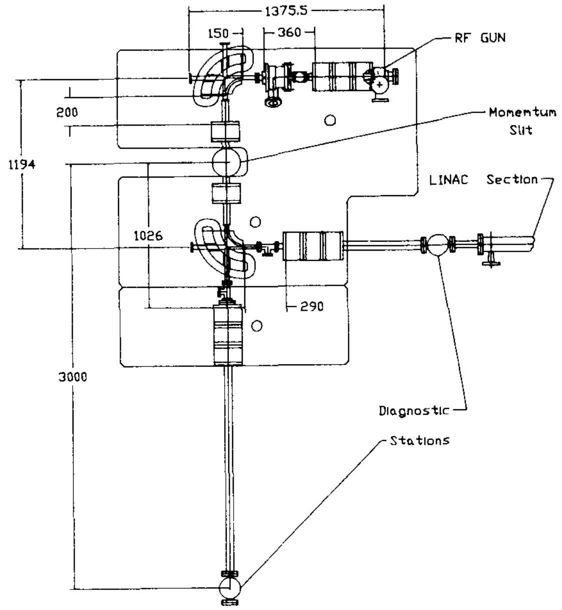

Table Captions

Table 1: Accelerating Section Design Parameters

Energy gain (unloaded), MeV	45
Energy gain (loaded, 50 mA), MeV	42.5
Operating frequency, GHz	2.856
Shunt Impedance, MΩ/m	53
Attenuation, nepers	0.6
Operating mode	$2\pi/3$
Structure diameter, mm	82.5
Beam aperture, mm	26.2 *to* 19.0
Structure length, mm	3050
Disc spacing, mm	35
Number of cells	87
Input β	0.995
Input power, MW	20

Table 2: RF Gun Design Parameters

Structure inner diameter, mm	83.08
Structure length, mm	78.75
Number of cells	$1\frac{1}{2}$
Operating frequency, GHz	2.856
Beam energy, MeV	4.65
Beam aperture, mm	20
Shunt Impedance, MΩ/m	57
Cavity Q	11800
Max. Surface electric field, MV/m	118
Average accelerating gradient, MV/m	66.6
Electric field on cathode, MV/m	100
Cavity stored energy, J	3.5
Cavity peak power, MW	5.3

Table 3: ATF Beam Parameters

Mode of Operation	*High*	*Low*	*Thermionic*
Energy, MeV	50	50	50
Peak Current, A	100	.006	10
Emittance $(\gamma\sigma_x\sigma_{x'})$, m-rad	3.5×10^{-6}	1×10^{-8}	3×10^{-5}
Electron pulse length, ps	6	6	> 10
Electron bunch separation, ns	12.5	12.5	.35
Klystron pulse length, μs	5	5	5