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COMMISSIONING OF THE NEPTUNE PHOTOINJECTOR*

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Abstract

The status of the commissioning of the rf photoinjector in the Neptune advanced accelerator laboratory is discussed. The component parts of the photoinjector, the rf gun, photocathode drive laser system, booster linac, rf system, chicane compressor, beam diagnostics systems, and control system are described. This injector is designed to produce short pulse length, high brightness electron beams. Experiments planned for the immediate future are described. Initial measurements of various beam parameters are presented.

1 THE NEPTUNE LABORATORY

The primary goal of the Neptune laboratory is the acceleration of a high brightness, relativistic electron beam in a plasma beatwave accelerator (PBWA), while maintaining the initial phase space density. [1] To this end, the main components of the lab are the high power, short pulse, two-frequency Mars CO_2 laser [2], and the rf photoinjector.

2 THE PHOTOINJECTOR

The Neptune photoinjector consists of many components. The most important of which are described below.

2.1 Accelerator Sections

The accelerator is a split system consisting of a photocathode gun, a drift space, and a booster linac. The gun is a 1.625 cell π-mode standing wave cavity produced by a BNL-SLAC-UCLA collaboration. [3] The gun has been conditioned up to an input power of 6.5 MW which corresponds to the planned on-axis peak field of 100 MV/m. The booster linac is a 7 and 2/2 cell π-mode standing wave structure. The linac design is that of a plane-wave transformer (PWT) which benefits from strong cell-to-cell coupling and large mode separation. [4] The linac has been conditioned up to the nominal operating power of 13 MW.

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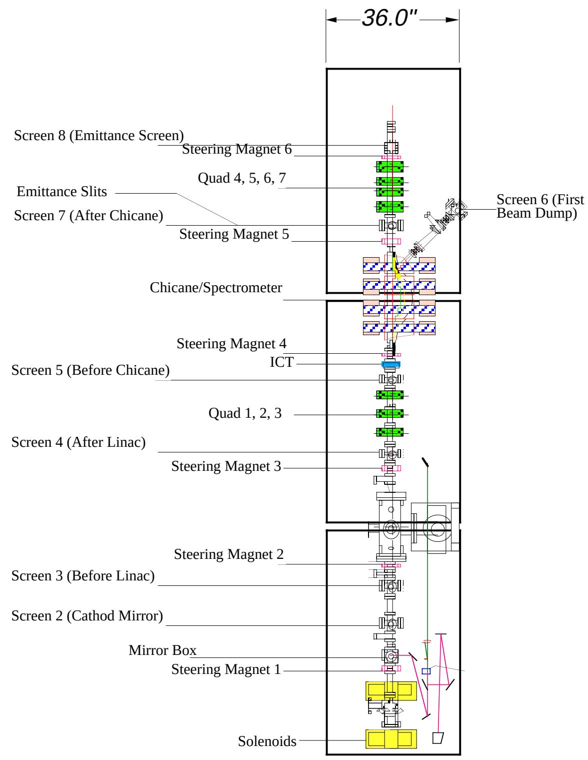

Figure 1: The Neptune Photoinjector Beamline

2.2 RF System

Low level rf is produced by a 38.08 MHz signal which is frequency multiplied 75 times up to S-band. After passing through a phase shifter, the signal is raised to over 400 W by a pulsed solid state amplifier. This signal is then used as the rf input to a SLAC XK-5 klystron. The klystron is pulsed by a modulator with a pulse length currently set to 4 μsec. The modulator was designed to produce a flat-top pulse, when fired by an SCR-triggered thyratron timed to the klystron rf input, impedance matched to the klystron at high voltage. [5] The klystron has output 22 MW pulses to the wave guide system on a consistent basis.

The rf power distribution system consists of vacuum wave guide separating power manipulating elements. The first of these is a circulator which protects the klystron from reflected power due to the impedance mismatch at the standing wave structures at the beginning and end of an rf pulse. The power is then split by a 4.77 dB divider sending two thirds into the PWT. After the split there are high power attenuators to control the power delivered to each accelerator. In addition the linac wave guide has a phase shifter to control the relative phase of the two structures.

2.3 Photocathode Drive Laser

The drive laser system begins with a 1064 nm mode-locked Nd:YAG laser which is matched into a 500 m long fiber to lengthen the pulse and yield a frequency chirp. The chirped pulse is then sent to a regenerative amplifier that increases the signal by a factor of one million. The chirp correlation is then removed and the pulse compressed by a grating pair. Adjustments to the grating pair allow control over the pulse length which is currently set at 3 psec (FWHM). At this point the pulse is frequency doubled by a BBO doubling crystal. The green laser light is then transported approximately 40 meters to the next BBO crystal which frequency doubles again to produce 266 nm light. The pulse energy in UV has been measured reproducibly at 130 μJ.

Due to the long transport length, a vacuum transport system has been constructed to hold beam optics and to combat fluctuations in transverse position. To handle long time scale (≥ 10 sec) beam drift, a feedback system consisting of motorized mirror mounts and segmented photodiodes functions in the transport system. This system is computer automated by iteratively reading the position of a beacon laser with the photodiodes (beam position monitor) and adjusting the motorized mirror accordingly.

2.4 Chicane Compressor

The compressor installed at Neptune was designed in part by scaling an L-band compressor designed for the TESLA Test Facility (TTF)[6]. As shown in figure 2, it consists of four dipole magnets which can be configured either as a compressor or a spectrometer. In compressor mode a negative correlation in longitudinal phase space caused by running off-crest in the PWT is removed by the difference in path length of particles of different momentum. The problem of excessive vertical focusing in the chicane has been addressed by adjusting the initial and final edge angles to approximately equalize horizontal and vertical focusing in the device. By switching off the first two dipoles, the second two are used as a spectrometer. The chicane in spectrometer mode has been used for preliminary beam energy measurements.

2.5 Beam Diagnostics

The main diagnostic used at Neptune for beam transport, spot size, and profile measurements is the phosphor screen. For this device phosphor is deposited on the downstream side of an aluminum foil mounted normal to the incident beam. A 45° mirror then directs light produced by the phosphor out to a CCD camera. From

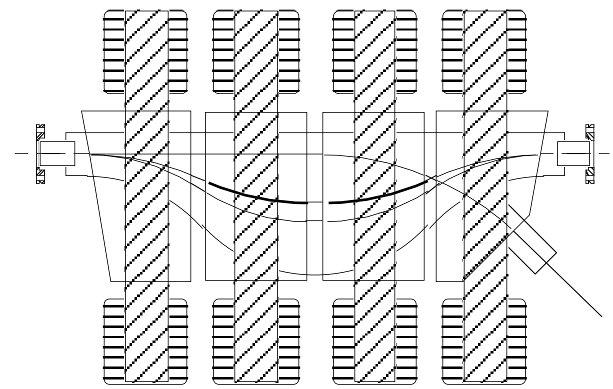

Figure 2: Chicane Compressor/Spectrometer

there the video data is digitized by a computer and analysis is preformed on the image. In addition to phosphor, beam spot screens using YAG crystals, which offer higher resolution and better vacuum properties, are active at Neptune.

To measure charge non-destructively we employ an integrating current transformer (ICT). This device produces data on a shot-to-shot basis and has been used at UCLA to measure charges from 10 pC to 5 nC [5]. For destructive bunch charge measurements Faraday cups mounted as beam dumps are used. The Faraday cups have been used for initial charge measurements at Neptune.

Transverse emittance measurements will be made using a slit based system [7]. In this system collimating slits are used to separate the beam into many beamlets whose intensity after propagation in a drift can be used to determine the phase space distribution of the initial beam.

To measure the longitudinal profiles produced at Neptune (< 1 psec after compression), a technique using coherent transition radiation (CTR)[8] will be employed.

2.6 Control System

The photoinjector control system begins with an Apple Macintosh computer. The computer has a video digitizing card which allows real time analysis such as dark current subtraction, spot size calculation, and emittance slit image analysis. Also, the computer is equipped with a GPIB interface which is used to import oscilloscope traces, and communicate with a GPIB controlled CAMAC crate. The CAMAC crate contains modules responsible for phosphor screen insertion, steering and quadrupole magnet control and read-back, chicane control, and rf attenuators and phase shifters.

3 PLANNED EXPERIMENTS

Before the PBWA experiment is ready to proceed, there is an opportunity to do experiments in the area of high brightness beam physics. Investigations in this domain will include parametric studies of the emittance compensation process, comparison of emittance measurement techniques, and studies on the compressibility of pulses in the chicane as well as emittance growth in the chicane due to space charge effects.

3.1 Emittance Compensation Studies

Recent theoretical work has given a prescription for producing a minimum in transverse emittance in RF photoinjectors [9]. By varying the key parameters in this process, i.e. beam aspect ratio, solenoid field strength, and bunch charge, we plan to experimentally check this theory.

3.2 Emittance Measurement Techniques

The space charge dominated behavior of high brightness beams produced at Neptune can be seen through examination of the RMS envelope equation for a beam in a drift.

$$\sigma_x'' = \frac{\varepsilon_n^2}{\gamma^2 \sigma_x^3} + \frac{4I}{\gamma^3 I_0 \left(\sigma_x + \sigma_y\right)} \tag{1}$$

Here the ratio of the space charge to emittance terms determines the character of the electron beam.

$$R = \frac{2I\sigma_0^2}{I_0 \gamma \varepsilon_n^2} \tag{2}$$

For typical Neptune parameters R >> 1 indicating a space charge dominated beam. Thus, any emittance measurement scheme based on beam propagation in a drift must take this ratio into account.

In the slit based measurement we see that the function of the slits is to produce beamlets for which this ratio is drastically reduced. For a uniform beamlet formed by a slit of width d, this ratio becomes

$$R_{beamlet} = \sqrt{\frac{2}{3\pi}\frac{I}{\gamma I_0}}\left(\frac{d}{\varepsilon_n}\right)^2 \tag{3}$$

For the slits installed at Neptune d = 50 μm and $R_{beamlet}$ << 1.

This emittance measurement system will be compared with the quadrupole scanning technique. In the quad scan procedure, the beam spot size is measured as a function of quadrupole field gradient. A purely emittance dominated beam under these conditions will behave such that the mean square beam size varies quadratically with the inverse focal length of the quadrupole lens. The transverse emittance is then calculated from the fit parameters of this curve.

We see from simulation how a space charge dominated beam can mimic the behavior of an emittance dominated bean in the quad scan procedure. Figure 3 shows this effect. At Neptune we plan to study this phenomenon and compare the results with an analytical model currently being developed.

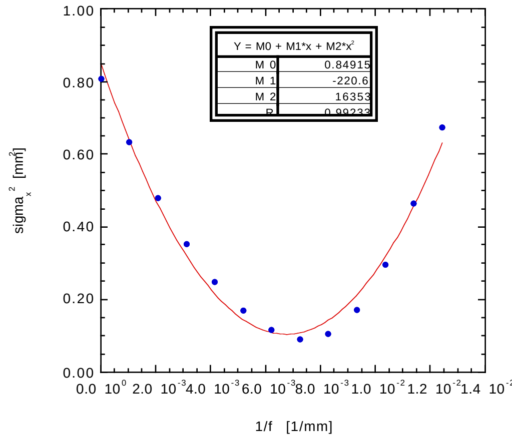

Figure 3: PARMELA simulation of a quad scan performed on a space charge dominated beam. The apparent emittance calculated from the quad scan is 4 mm mrad. The RMS emittance of the beam is actually 1.6 mm mrad.

3.3 Compressor Studies

In addition to basic studies on the compressibility of electron pulses, we plan to investigate the phenomenon of emittance growth in bends. Experiments in this area will be complimented by simulations using a three-dimensional code based on Lienard-Wiechart potentials [10].

4 INITIAL COMMISSIONING

The Neptune photoinjector was commissioned and photoelectrons were observed in early March 1999. The beam was accelerated by both structures and the chicane was used to measure an initial energy of 12 MeV.

5 REFERENCES

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