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Development of the Alternate Entry Port for the ATF*

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Abstract

We discuss a second entry port for the Accelerator Test Facility (ATF) injection system at Brookhaven National Laboratory, which consists of a photocathode rf gun and a straight - ahead beamline directly into the 50 MeV linac. The proposed second entry port should improve the beam quality and lower the emittance needed for FEL (Free Electron Laser), and laser - acceleration experiments. A discussion on the laser driven high brightness photoelectrons through the primary entry port (a low energy 180 degrees achromatic double bend transport line) now in operation, and a beam analysis for the proposed secondary port is also given.

I. INTRODUCTION

The high brightness laser driven photoelectron beams (with low emittance and high current) are required for new methods of acceleration such as FEL, IFEL (an inverse free-electron laser) and future development of linear colliders. To achieve high brightness and rapid acceleration, an rf gun operating at 2.856 GHz, with 1-1/2 cells, π- mode resonant, disc-loaded structure (with cathode placed at the start of the first 1/2 cell), has been designed and operating as the injector for the two *S*-band linac sections at the BNL Accelerator Test Facility (ATF). The cathode is illuminated with a frequency quadrupled Nd:YAG laser with photon energy of 4.65 MeV at the gun exit.

The Accelerator Test Facility at BNL is an experimental Facility for accelerator and beam physics experiments. A major research interest is in the interaction of laser driven photoelectrons with the electromagnetic fields. ATF's present injection system consist of a photoelectron gun and a low energy transport beamline which consists of two sets of quadrupole triplets and a 180° achromatic double bend, (Fig. 1). The photoelectrons are ejected from a photocathode rf gun into the transport beam line and then accelerated through 2 S - band linac sections to 50 MeV [1,2]. The linac consists of two $\pi/3$ - mode, 3.05 m long, disc loaded, travelling wave SLAC linear accelerator sections that was produced at IHEP, Beijing, China. The gun and the linac are driven by the same XK5 klystron, delivering about 25 MW of peak power with a 3.5 micro-second pulse at 2.856 GHz [2].

With the existing injection system, the beam diverges quickly at the gun exit and gets large in going through the double bend transport line into the linac [3,4]. We have considered and studied various schemes [6] and will present some results for the proposed ATF alternate injection system in section II. A summary and references are given in section III.

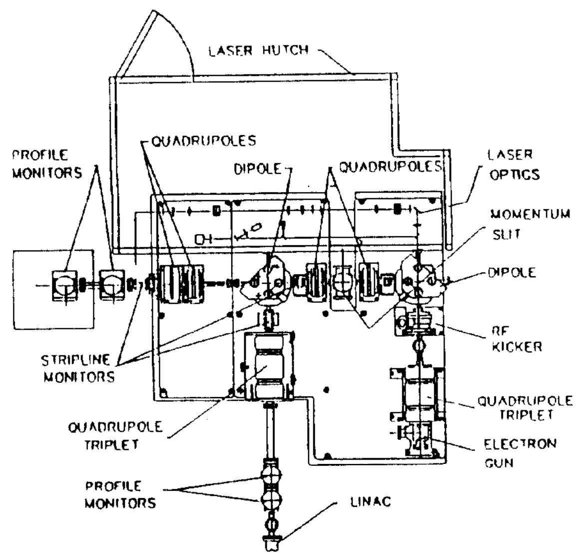

Figure 1: Sketch of the BNL ATF injection system. The transport beamline from the gun to the linac entrance showing the positions of the magnetic elements.

II. ALTERNATE INJECTION SYSTEM

We have considered various schemes to improve the beam quality and preserve the low emittance and high brightness beam needed for experiments at ATF [6]. In this section we present some of our calculations and simulation results obtained for a 2nd entry port for ATF. The alternate (straight-ahead) injection system consists of a solenoid + a gun + solenoid combination that is placed directly into the linac.

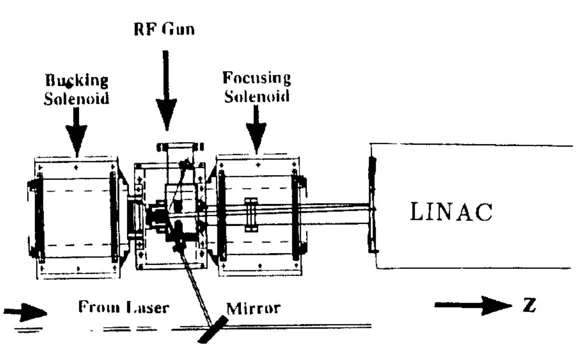

Figure 2: Sketch of the alternate injection system for ATF. A solenoid + gun + solenoid (gun+s) combination is placed in line with the linac. (Not scaled).

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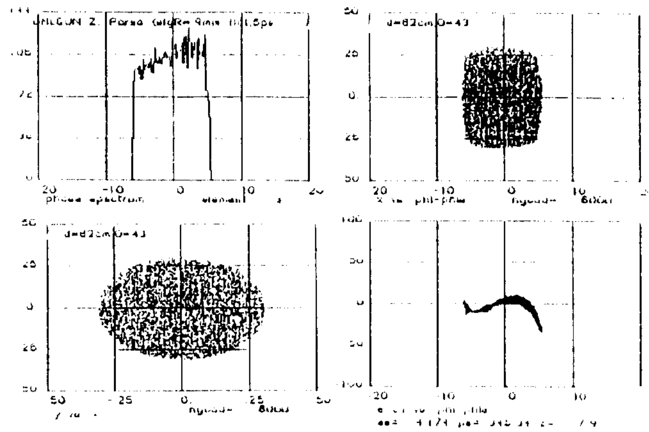

Figure 3a: Shows the beam profile at $z = 7.9cm$ (exit of the gun cavity). From the top in c.w.direction: phase spectrum, x vs change in phase, y vs x profile and change in energy vs change in phase with program PARMELA.

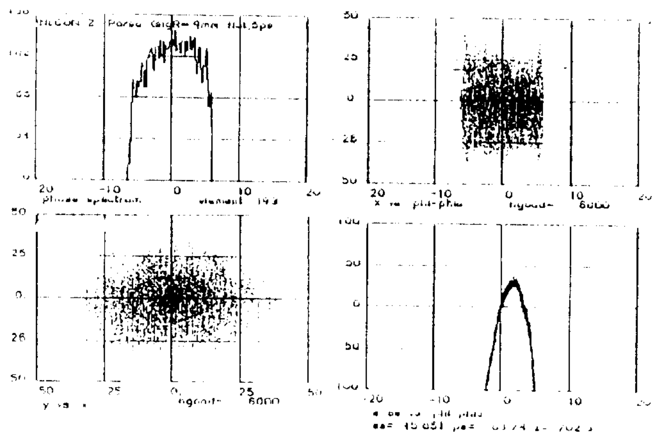

Figure 3b: Shows the beam profile at $z = 702.3cm$ (the linac exit). From the top in c.w.direction: phase spectrum, x vs change in phase, y vs x profile and change in energy vs change in phase with program PARMELA.

This scheme would allow the production of the low emittance and high brightness beam needed for the experiments and preserves the present injection system which can be used alternatively for diagnostic measurements etc. Where the beam is injected from a 2nd entry port (using a 2nd gun) directly into the linac without going through the bending magnets.

Selections of **d** the distance from the gun (cathode) to the linac entrance and solenoid strength are important and would effect beam quality (see Section III). For other injection schemes and a more detailed analysis see references. In this analysis the fields off axis for solenoids are calculated to sixth order using the expansions:

$$B_z(z,r) = B_z(z,0) - \frac{r^2}{4}\frac{d^2B}{dz^2} + \frac{r^2}{4}\left(\frac{d^4B}{dz^4}\frac{r^2}{16} - \frac{d^6B}{dz^6}\frac{r^4}{576}\right) \qquad (1)$$

$$B_r(z,r) = -\frac{r}{2}\left(\frac{dB}{dz} - \frac{d^3B}{dz^3}\frac{r^2}{8} + \frac{d^5B}{dz^5}\frac{r^4}{192}\right)$$

III. BEAM DYNAMICS AND ANALYSIS

In our analysis of the beam from cathode through the linac exit we have considered various initial charge distributions, laser spot sizes (σ_r), laser pulse lengths ($2\sigma_z$), field on the cathode E and accelerating field of the linac, etc.[6]. Table 1 illustrates some of our results obtained with the initial parameters of interest for ATF and the proposed UVFEL project at BNL. For example with initial $E = 100MV/m$ on the cathode, laser pulse length ($2\sigma_z$) of 10 ps, and varied spot sizes (e.g. 0.9 mm), and various values of **d** (e.g. 62 cm, the distance from cathode to linac entrance), solenoid strength of 2.2 KG and initial phase of 43 degrees we can preserve the beam quality and achieve high brightness, low emittance beam at the linac exit, which is needed for the FEL and laser acceleration experiments at ATF. With program PARMELA [5] With σ_r = 1mm and 0.9 mm (uniform beam distribution) we obtained beam emittance of few tenths of cm-mrad with energies of about $46MeV$ and brightness ($B = I^{peak}/\pi\epsilon_x^N\epsilon_y^N$) of orders of 10^{13} for the beam emerging from the exit of the linac, (Fig.4). We have used 10 ps pulse length in our analysis since $\sigma_z = 5$ ps is the value noted obtainable at ATF [1].

For $B_0 = 2.14$KG, $\sigma_z = 5$ ps, $\sigma_r = 1$ mm, $Q = 1$nC and an initial uniform distribution, the beam energy and emittance at the linac exit become $w = 46$ MeV, $\epsilon_x^{N,rms} = .32$ and $\epsilon_y^{N,rms} = .276$. Whereas for the same set of parameters and an initial gaussian distribution the beam emittance grows larger, e.g. at the linac exit. How easy is the production of the uniform distribution (flat beam) depends on the quality and bandwidth of the laser [1]. For detailed beam analysis with Gaussian and Rician distributions see e.g. [1,6].

Fig. 4 shows the change in the beam size along the beamline from cathode through the linac. As can be seen the beam converges to a waist in the linac. Where the change in the solenoid strength or **d** would shift the position of the beam waist in the linac and would change the beam parameters. For example a 2% increase in the solenoid strength will increase the emittance from ($\epsilon_x^{N,rms} = .278$, $\epsilon_y^{N,rms} = .243$) to ($\epsilon_x^{N,rms} = .390$, $\epsilon_y^{N,rms} = .333$) at the linac exit. keeping all other parameters fixed [1].

For the proposed alternate injection system for ATF, a pair of solenoids are placed before and after the gun to compensate the beam emittance dilution due to the space charge, such that the coil proceeding the cathode bucks the field due to the second solenoid and produces a zero field on the cathode. To avoid beam loss through the linac a proper matching of the beam into the linac is crucial.

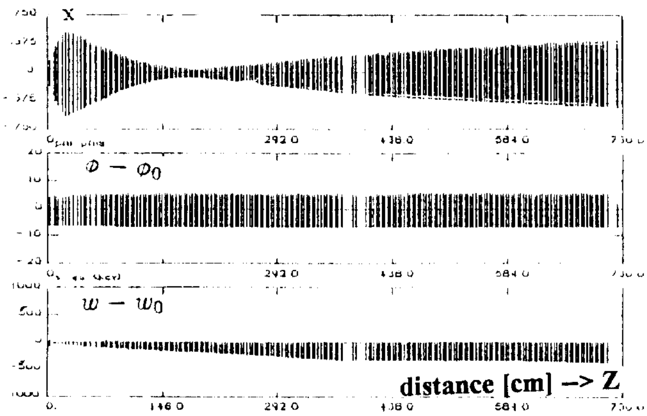

Figure 4: Shows the change in position x [cm], phase $\phi - \phi_0$ [degree] and energy $w - ws$ [KeV] of particles at each element location, from the cathode through the linac exit. With 2.2 KG solenoid, $d = 70cm$, $\sigma_r = .9mm$ and $\sigma_z = 5ps$.

IV. SUMMARY

We presented an alternate injection system for the ATF at Brookhaven National Lab, using a pair of solenoids and an rf gun placed directly into the linac. Earlier results showed that with the present injection system at ATF the beam become too large through the double bend transport line, leading to a large emittance growth and a large beam loss. With solenoid+gun+solenoid straight injection into the linac scheme we can reduce the emittance dilution due to space charge forces, and produce the beam needed for FEL, IFEL and other laser acceleration experiments. We obtained small emittance (few tenths of cm-mrad) and high brightness of orders of 10^{13}. We note that a proper beam matching at the linac entrance is crucial so as to avoid beam loss through the linac. The effects of variations in the solenoid strengths and d the distance from the cathode to the linac entrance can be detrimental to the beam quality along the transport line and through the linac. The beam converges into a waist after it enters into the linac. The position of this waist changes with the change in initial parameters such as the solenoid strength and the distance between the cathode and the linac entrance. To avoid beam loss or emittance dilution, there must be a careful control of the parameters such as the length and strength of the solenoids, laser spot size and pulse length, distance between the cathode and linac entrance, the accelerator phase and accelerator field. In this analysis the fields off axis for solenoids were calculated to 6th order.

VI. REFERENCES

*Work performed under the auspices of U.S. Dept.of Energy contract DE-AC02-76-CH00016.

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Table 1: ATF Solenoid+Gun+Solenoid+Linac system - simulation parameters.

Number of Solenoids	2
Length of Solenoid [cm]	15
Radius of Solenoid [cm]	6
B_0 Solenoid [KG]	2.2
Initial phase [degree]	43-45
Laser spot size σ_r [mm]	.9, 1 ....
Laser Pulse Length ($2\sigma_z$) [ps]	10
RF Frequency [GHz]	2.856
Radius of Aperture [cm]	1.0
Field on the Cathode [MV/m]	100
Charge [nC]	1
with d [cm]	62 - 70
Linac Accel. Gradient (Ave.) [MV/m]	7.0
At Linac Exit: Energy [MeV]	46 - 47
dp/p [%]	0.18 - 0.2
ϵ^N [π cm-mrad]	0.2 - 0.4
Brightness ($B = I^{peak}/\pi\epsilon_x^N\epsilon_y^N$)	x10^{13}