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REDUCTION OF BEAM CORKSCREW MOTION ON THE ETAII LINEAR INDUCTION ACCELERATOR*

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Abstract

The ETAII linear induction accelerator (6MeV,3kA,70ns) is designed to drive a microwave free electron laser (FEL) and demonstrate the front end accelerator technology for a shorter wavelength FEL. Performance to date has been limited by beam corkscrew motion that is driven by energy sweep and misalignment of the solenoidal focussing magnets. Modifications to the pulse power distribution system and magnetic alignment are expected to reduce the radius of corkscrew motion from its present value of 1 cm to less than 1mm. The modifications have so far been carried out on the first 2.7 MeV (injector plus 20 accelerator cells) and experiments are beginning. In this paper we will present calculations of central flux line alignment, beam corkscrew motion and beam brightness that are anticipated with the modified ETAII.

Introduction

Previously ETAII has successfully operated with 6 MeV beam energy, accelerated beam current up to 3 kA (70ns FWHM) and driven a 140 GHz FEL with peak power in the range 200-400 MW. [1,2] However the FEL output pulse width was generally much narrower (5-10ns) than the beam pulse due to the corkscrew motion of the electron beam. [3,4] The corkscrew motion is a differential rotation of the beam centroid between the center and leading and trailing edges of the pulse. It is driven by the combination of energy sweep and misalignment of the solenoidal focusing field and at a fixed axial location leads to a time dependent sweeping of the beam centroid that cannot be corrected with static steering coils. Consequently we have embarked on a program to reduce energy sweep and improve magnetic alignment before proceeding further with FEL experiments.

From the viewpoint of FEL operation beam quality is characterized by brightness (defined here as $J = I/(\beta\gamma)^2 V_4$), energy sweep and spatial sweep (or corkscrew amplitude which we will define below). Past performance and our near term goals for these parameters are given in Table 1 below. Brightness of the entire beam has been measured by analyzing beam radius as a function of focusing strength of upstream solenoids[5]. A brightness value of 1×10^8 A/m^{2}rad^2 is adequate for a microwave FEL and has already been exceeded with the measured value 6×10^8 A/m^{2}rad^2. However a brightness 2×10^9 A/m^{2}rad^2 is required for a micron wavelength FEL and this is our near term goal. Energy sweep of ±1% or less is desirable for limiting the phase of corkscrew motion and for satisfying FEL resonance. Previously an energy sweep of ±1% has been maintained for only 13 ns out of the 70 ns FWHM. Our near term goal is to extend this to 30 ns by modifications to the pulse power distribution system which improve the flatness of accelerating pulse applied to the cell gaps[6]. Ultimately we hope to extend the ±1% energy flattop to 50 ns by modifying the shape of the beam current pulse to compensate for impedance variation of the ferrite in the accelerating cells. Efficient FEL operation requires that the magnitude of beam spatial sweep be controlled to approximately ±1mm at the exit of the accelerator whereas previously the spatial sweep has been an order of magnitude higher - ±1 cm. Improvements in flux line alignment together with reduced energy sweep are expected to allow us to reach our goal of ±1mm.

Table 1: Beam quality parameters for ETAII

parameter	status (12/89)	goal
brightness (A/m^{2}rad^2)	6×10^8 @ I= 1.3 kA	2×10^9 @ I= 1.5 kA
energy sweep	±1%, 13ns	±1%,30ns
corkscrew amplitude	±1cm,50ns	±1mm,30ns

Flux Line Alignment

The electron beam in ETAII is focused by a continuous solenoidal channel interrupted only by gaps for acceleration, insertion of beam position monitors and vacuum pumping. The typical strength of solenoidal field is 100 to 500 G. A sin/cos coil pair is wrapped around each solenoid to correct for transverse dipole field errors described in the paper by W. Nexsen.[7] The magnitudes of transverse displacements and equivalent tilts of the magnetic axis relative to a straight line mechanical reference axis have been measured with the pulsed stretched wire technique.[8] The transverse displacement errors are ±.5mm horizontally and ±.25mm vertically. The magnitude of transverse displacement errors is minimized by adjusting the axis of an entire cell block of ten acceleration cells, however there is no provision for adjustment of the transverse displacement of individual cells once they have been assembled into cell blocks. Sin/cos coil currents correct the magnetic axis of each solenoid to approximately ±1mrad standard deviation error. The field solver portion of our expert control system MAESTRO[9] has been used to calculate the trajectory of the central magnetic flux line from the transverse displacements and winding errors measured with the stretched wire. Results are shown in Fig. 1(a) without and (b) with the sin/cos correction coils turned on. The magnitude of flux line wander is reduced an order of magnitude with the sin/cos coils, from ±3.5mm to ±200 microns. Residual errors with the sin/cos coil currents on are due to several effects; (1) the overlap of the sin/cos coils with the dipole winding errors is not perfect, (2) there are residual errors in the magnitudes of

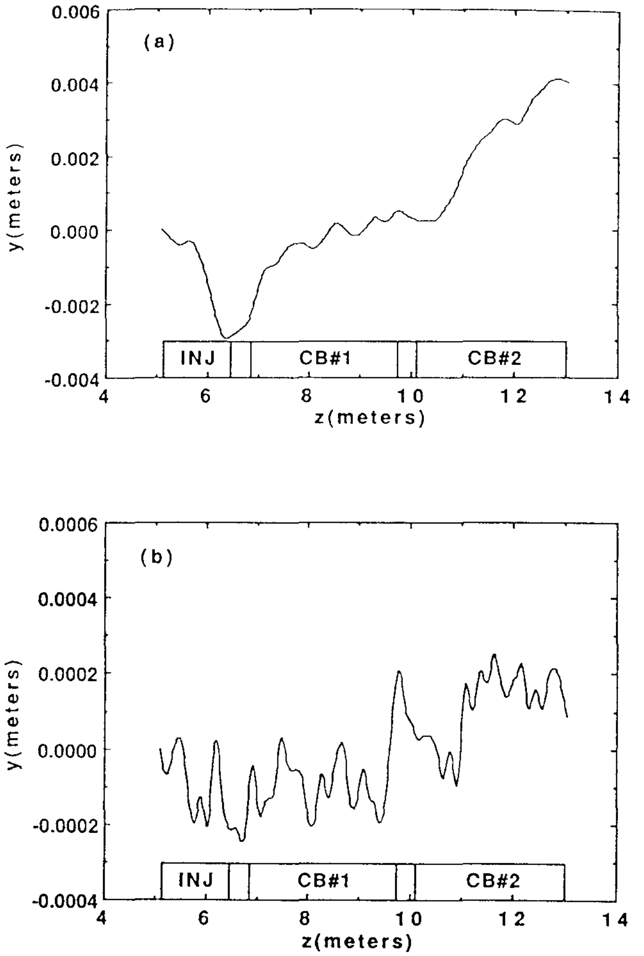


Fig.1. Mapping the central flux line of ETAII, (a) without and (b) with sin/cos correction coils.

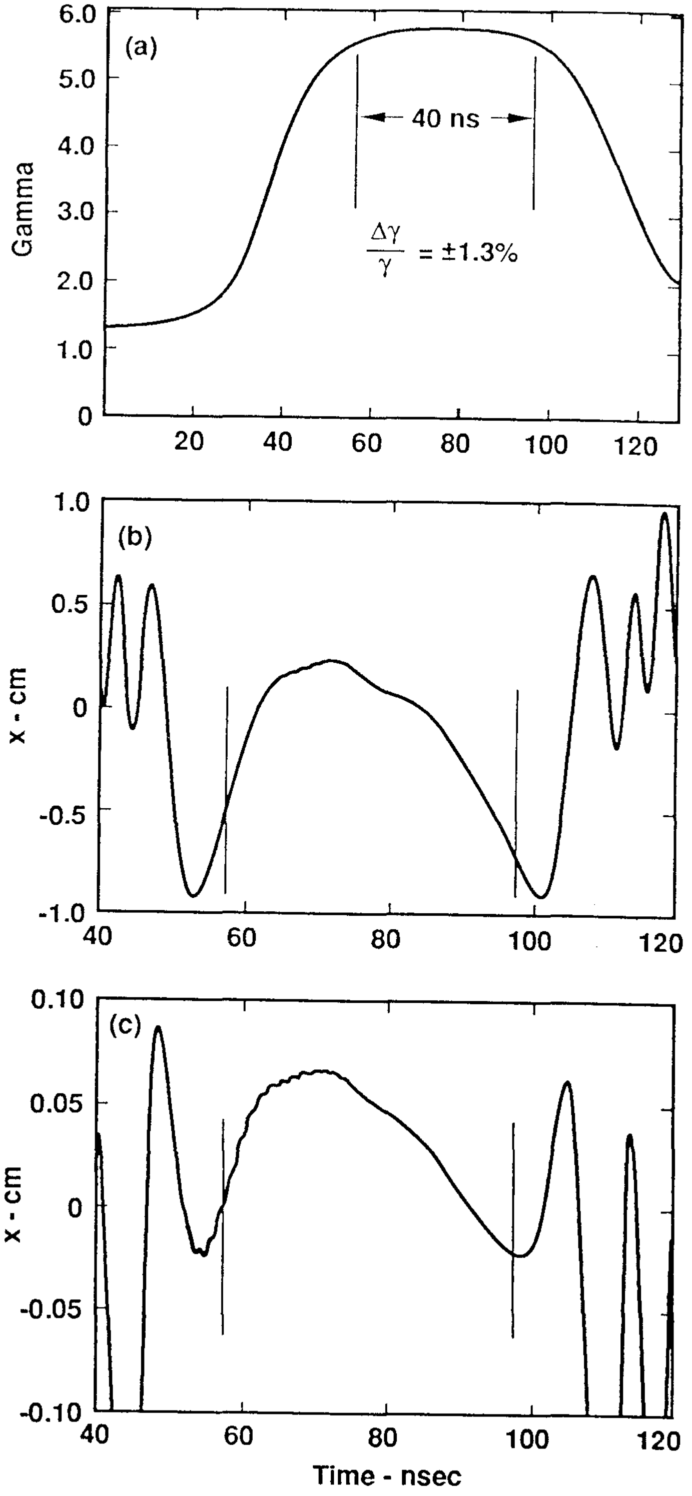


Fig. 2. Anticipated corkscrew motion of the ETAII electron beam. Gamma versus time (a), transverse x position versus time at the end of 20 cells (b)without and (c) with sin/cos coils.

the sin/cos coil currents and (3) the sin/cos coils correct for angular misalignments of the magnetic axis but not for transverse displacements. Reduction of the transverse displacement errors could be facilitated by incorporating the stretched wire alignment technique into the assembly of the ten cell blocks.

Corkscrew Motion

The magnitudes of magnetic field errors described in the last section and the energy sweep anticipated with the new pulse distribution system have been used as input to the BREAKUP code[10] which then calculates the corkscrew motion of the beam centroid. Results are shown in Fig. 2. The energy sweep is ±1.3% for the 40 ns indicated in Fig. 2(a) and the corresponding corkscrew motions are indicated in Fig. 2(b) without and Fig. 2(c) with sin/cos correction coils. Without correction coils the corkscrew amplitude is ±4 mm and with correction coils is reduced to ±0.4 mm. The calculation was done for the present configuration of injector plus 20 cells. Calculation for the full sixty cells predicts a corkscrew amplitude of ±.5 mm with correction coils.

A field tuning algorithm is being incorporated into MAESTRO to minimize the corkscrew amplitude "A" defined at a given axial location by

$$<A^2> = < x^2 + y^2 >$$

where x and y are the beam centroid coordinates measured by beam position monitors and < > denotes time averaging. Fig. 3 shows a BREAKUP calculation of "A" versus the current in a single sin/cos correction coil with the optimum current at the minimum value of A.

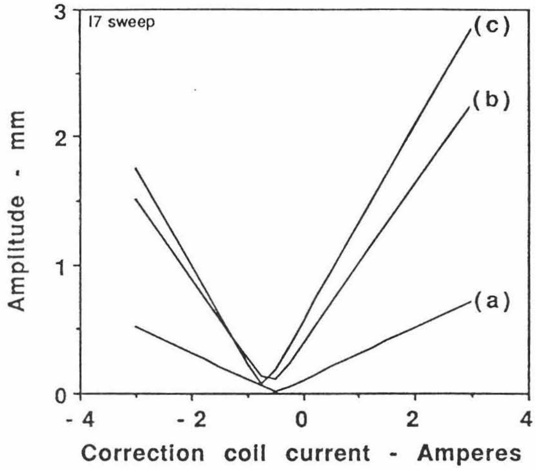
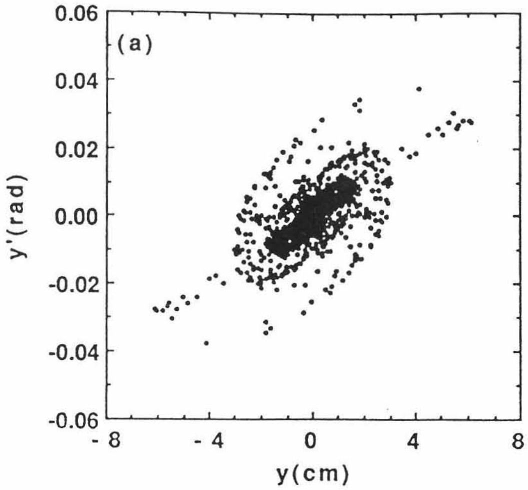


Fig. 3. Corkscrew amplitude (a) at the end of the injector, (b) at the end of 10 acceleration cells and (c) at the end of 20 acceleration cells versus current in a single sin/cos correction coil.

Accelerator Tune and Brightness

Whole beam brightness has previously been measured on ETAII at 6 MeV by measuring the beam radius as a function of focussing strength of upstream solenoids.[5] With the present injector plus twenty cell configuration the beam energy is reduced to 2.5-3.0 MeV, space charge forces totally dominate emittance, and this technique is no longer viable. Instead we will use the pepper pot technique. Analysis of our previous data has revealed a tune dependent generation of halo electrons which degrade beam brightness.[5] The degradation occurs when there is an approximate resonance condition between the cyclotron wavelength and an integer number of acceleration cells. Calculations of beam scatter plots at the end of twenty cells are shown in Fig. 4(a) for the old tune and (b) for a new tune which avoids resonances. The brightness of the beam is predicted to be improved by more than a factor of four.



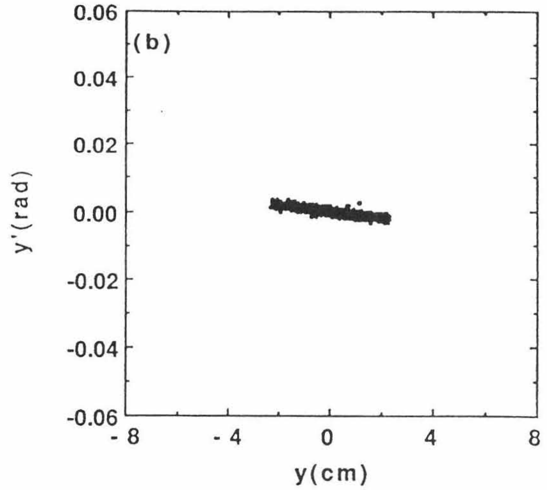


Fig. 4. Reduction of halo electron production with choice of accelerator tune, (a) resonant and (b) non-resonant tune.

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