A HIGH PEAK CURRENT SOURCE FOR THE CEBAF INJECTOR*

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Abstract

The CEBAF accelerator can drive high power IR and UV FELs, if a high peak current source is added to the existing front end. We present a design for a high peak current injector which is compatible with simultaneous operation of the accelerator for cw nuclear physics (NP) beam. The high peak current injector provides 60 A peak current in 2 psec long bunches carrying 120 pC charge at 7.485 MHz. At 10 MeV that beam is combined with 5 MeV NP beam (0.13 pC, 2 psec long bunches at 1497 MHz) in an energy combination chicane for simultaneous acceleration in the injector linac. The modifications to the low-energy NP transport are described. Results of optical and beam dynamics calculations for both high peak current and NP beams in combined operation are presented.

Introduction

The CEBAF superconducting accelerator will have unique capabilities for the acceleration of high-intensity, high-quality electron beams. A proposal is being developed to apply these capabilities to obtain beams suitable for driving high power infrared and deep ultraviolet FELs. The CEBAF injector linac would provide the IR FEL with 50 MeV beam, while the UV FEL would use 400 MeV beam from the CEBAF north linac [1].

FEL operation requires the addition of a high peak current source to the CEBAF front end. This source consists of a photoemission gun, a bunching and preaccelerating system, and a chicane to combine the beam with the lower current NP beam for simultaneous operation. The new beam source produces 2 psec long pulses at 7.485 MHz with 60 A peak current and a rms normalized emittance smaller than 15 π mm mrad. This injector will be located in an existing drift region between the NP beam source and the existing injector cryomodules. Therefore a beam bypass transport must be provided for the NP beam. A design of the NP bypass and its PARMELA [2] simulation are presented together with the high peak current source (see Fig. 1) and the results of the high space charge beam transport calculations.

Modification of the NP Beam Transport

In the present configuration of the CEBAF front end the beam drifts at an energy of 5 MeV between the NP cryounit and the first cryomodule of the injector linac [3]. The new high intensity source will be inserted in this presently 14.2 m long drift space. Therefore, a beam bypass transport around the new source into the CEBAF injector linac will be needed for the NP beam. A design for a matched bypass transport, which includes high peak current and NP beam combination, has been developed (see Fig. 1). It requires four dipoles and seven quadrupoles. In order to preserve the beam quality, the beam line is designed to be first-order achromatic and isochronous, using the transport code DIMAD [4]. The existing CEBAF injector was first simulated using PARMELA to calculate the parameters of the beam exiting the cryounit to be used as input to the bypass. The DIMAD results (see Fig. 2) show the beam parameters through the NP bypass.

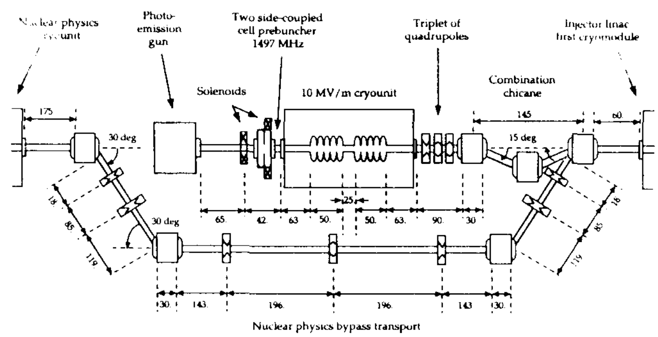

Fig. 1 High peak current source and NP bypass transport (dimensions in cm).

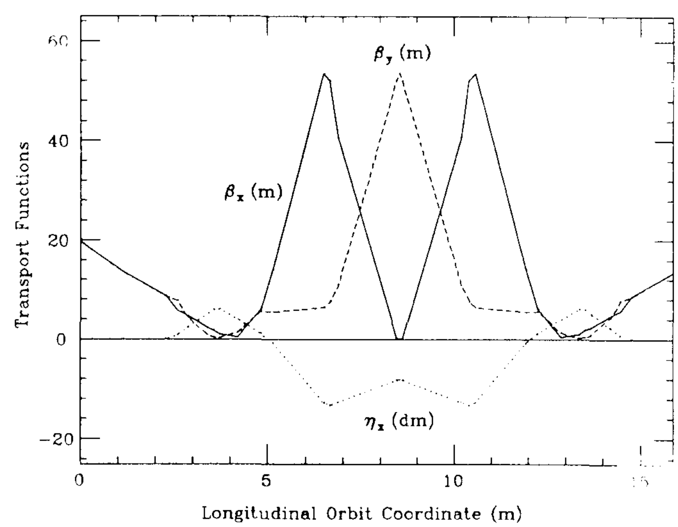

Fig. 2 NP beam parameters in the bypass transport.

The CEBAF injector with and without the NP bypass was simulated using PARMELA to check its performance. Figure 3 presents the longitudinal phase space of the NP beam exiting the NP cryounit and entering the injector linac with and without the bypass. One can see that these two different transports produce identical longitudinal results. This demonstrates that undegraded beam quality for the

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NP beam will be maintained with the beam bypass. The PARMELA results also show that adequate transverse focussing is obtained with the bypass transport; the beam actually has improved transverse confinement with the bypass replacing the 14.2 m drift.

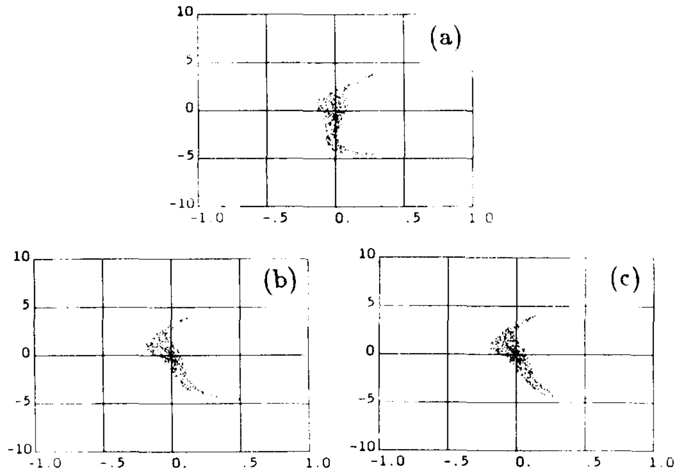

Fig. 3 NP bunch longitudinal phase space (keV vs. deg): (a) exiting the NP cryounit, (b) without bypass, entering the injector linac, (c) with bypass, entering the injector linac.

In addition, the PARMELA calculations demonstrate that the NP beam does not need any additional focussing downstream of the bypass to travel through both linac cryomodules (see Fig. 4).

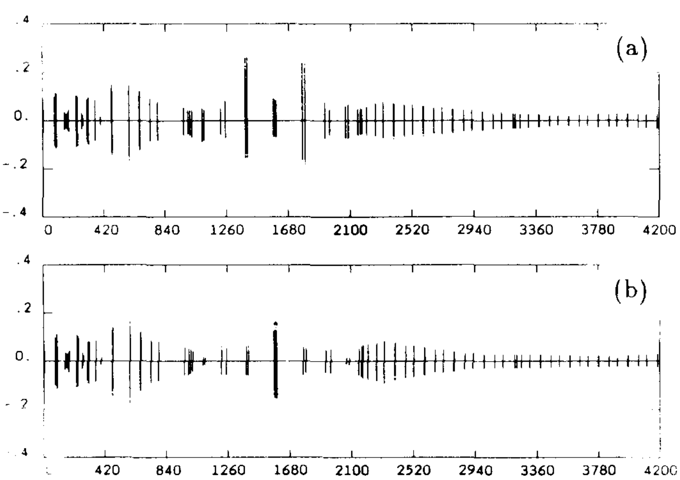

Fig. 4 NP beam envelope from the electron gun to the end of the injector linac, with the bypass transport (cm): (a) horizontal, (b) vertical.

Description of the High Peak Current Source

The solution adopted to deliver pulses of 120 pC and 2 psec duration employs a 500 kV DC electron gun with a photoemission cathode [5], followed by a room temperature prebuncher, a 10 MeV/m CEBAF two-cavity cryounit (quarter-cryomodule) which both bunches and accelerates [6], and an injection chicane to combine the beam with the lower energy NP beam prior to acceleration in the CEBAF injector linac (see Fig. 1). The photoemission gun with its associated laser system generates a 7.485 MHz train of low-emittance bunches containing sufficient charge, but with a 4σ pulse width of 100 psec. These long-duration but otherwise acceptable bunches are further bunched by the room temperature prebuncher, by the two superconducting cavities in the cryounit, and by the injection chicane to the desired microbunch length of 2 psec at the combination point. Two solenoids between the electron gun and the 10 MeV/m cryounit ensure that the beam is transversely confined through the RF bunching process. Immediately following the 10 MeV/m cryounit, an asymmetric triplet of quadrupoles matches the beam optics to the injection chicane in a manner which does not require further focussing downstream of the combination point; no focussing is needed until the end of the second (and last) injector cryomodule.

Calculations of Space Charge Dominated Beam Dynamics in the High Peak Current Source

The bunching scheme for our source was developed using PARMELA. We implemented the code with a point-by-point space charge calculation subroutine [7] which is, we believe, more appropriate than the original PARMELA subroutine (which uses a mesh method) for the very short high peak current bunches our source will deliver. Simulations of the photoemission gun show that its performance depends strongly on the size of the cathode (of the order of a few mm), but the resulting normalized emittance remains well below the 15 mm mrad FEL specification (simulations obtain 4 to 10 mm mrad). These simulations also demonstrate the capability of the gun to emit bunches with a 4σ momentum spread as low as 0.6%. Typical calculations assume a 3 mm radius beam spot, a 10 mm mrad rms normalized emittance, a 4σ momentum spread of 0.6% and a 4σ pulse length of 100 psec, at the output of the electron gun.

The wide aperture of the CEBAF superconducting cavity (radius of 3.5 cm) permits us to expand the beam radially to about 1 cm of radius, reducing both transverse and longitudinal space charge effects. Transverse focussing requires two solenoids before the 10 MeV/m cryounit and a triplet of quadrupoles before the combination chicane. This triplet counters the focussing effects of the combination chicane dipoles and matches the beam to the end of the injector linac. Figure 5 shows the horizontal and vertical beam envelopes as calculated with PARMELA, from the gun output to the injector linac end.

Since the beam is bunched to a length much shorter (< 1 mm) than its width, longitudinal phase space dilution is a significant concern, particularly at lower energies. Bunching is obtained through phase control of both prebuncher and cryounit. The simulations show an emittance increase from 10 keV deg to 24 keV deg from the gun to the cryounit, as the beam bunches from 100 psec to 30 psec. Bunching continues through the cryounit and the chicane ($M_{56} = -8.7$ cm), where a final magnetic compression from

8 to 2 psec occurs. Figure 6 shows the high peak current at the cryomodule entrance (10 MeV), after compression of a 160 pC, 100 psec bunch, and combination with the NP beam. The design specifications of 120 pC within the central 2 psec (1.1°) are exceeded, with a 25 keV deg emittance. The pulse duration stays constant through acceleration to 50 MeV in the injector linac cryomodules, but the longitudinal rms emittance can increase to 30 keV deg depending on the phase of the beam. If driven on-crest ($\phi = 0$), the high peak current bunch receives an energy tilt with a full width as large as 400 keV (still acceptable for the FEL). Space charge forces increase the energy spread. This effect can be countered with off-phase operation; however, that is constrained by matching to NP requirements. Future studies will optimize phase-matching for concurrent operation.

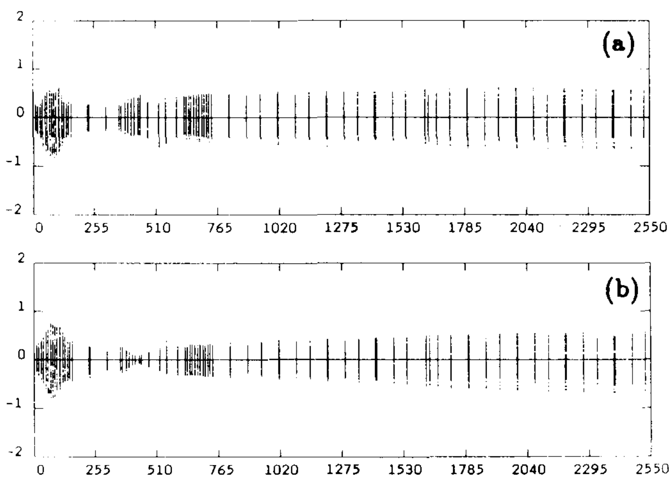

Fig. 5 High peak current beam envelope from the photoemission gun to the end of the injector linac (cm): (a) horizontal, (b) vertical.

Summary

Space charge dominated dynamics calculations have shown that the design of our high peak current source meets the requirements of the CEBAF FEL proposal. This source can be inserted in the front end of the CEBAF accelerator with simple modifications of the existing injector, including a transport bypass for the NP beam. Undegraded simultaneous operation is possible. Further efforts will be concentrated on optimizing both beams and matching their energies for various simultaneous operations.

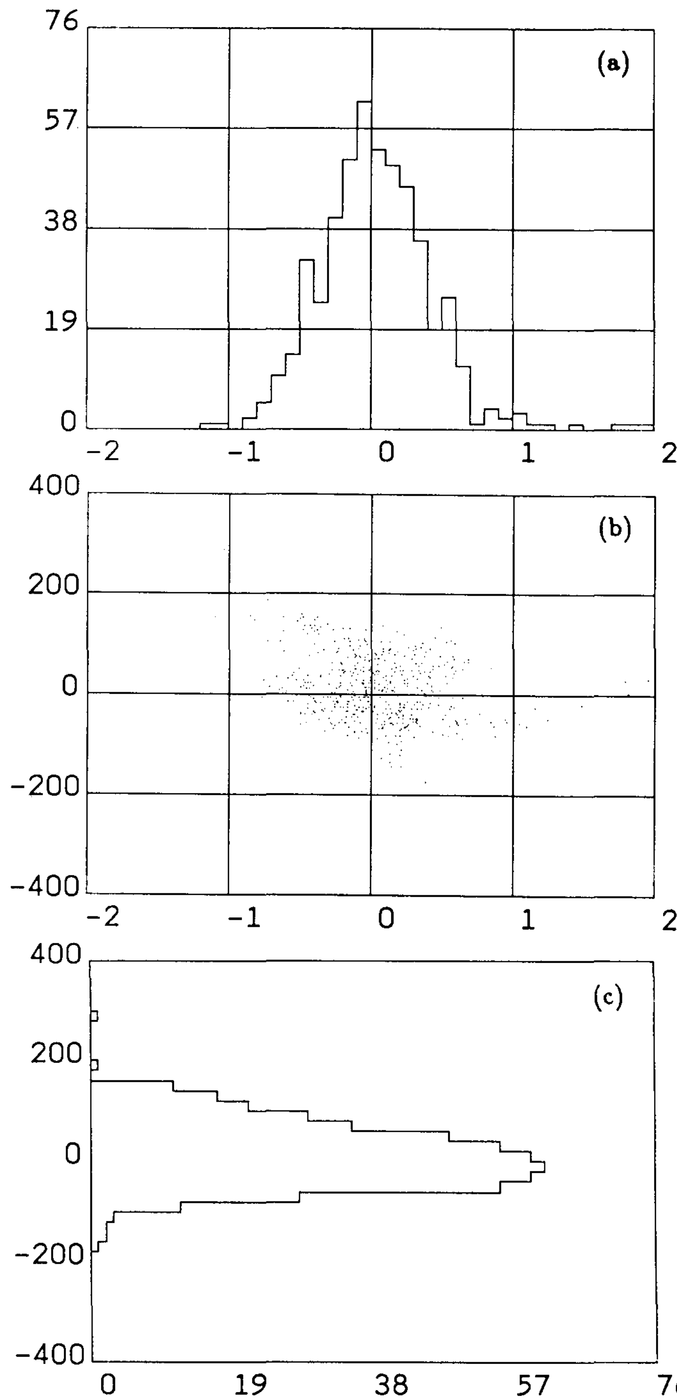

Fig. 6 Output of the high peak current source at the entrance to the injector linac: (a) phase spectrum (deg), (b) longitudinal phase space (keV vs. deg), (c) energy spectrum (keV).

References

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