FORMATION OF THE ELECTRON BUNCH LONGITUDINAL PROFILE FOR COHERENT ELECTRON COOLING EXPERIMENT*

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Abstract

Proof-of-principle experiment of the coherent electron cooling (CeC) is ongoing at Brookhaven National Lab. CeC mechanism utilizes amplification of density modulation, induced by hadrons, by an FEL structure. To fully utilize electron beam cooling capacity we need uniform longitudinal beam profile. In this paper we present two frequency injector system tuned for this requirement.

INTRODUCTION

The principle of the coherent electron cooling is the following [1]. The hadrons imprint their distribution onto the co-propagating electron beam thus creating a density modulation of the electron bunch. This modulation is amplified by a FEL structure and electric field is significantly increased. Due to the longitudinal dispersion a hadron arrives into the accelerating or decelerating phase of the field depending on its energy. With properly tuned system a net reduction of energy spread is obtained.

The cooling rate depends on the strength of the longitudinal space charge field, i.e. on the FEL gain, which depends exponentially on the peak current distribution of the electron bunch. Therefore it is desirable to have as much gain as possible. However, reaching saturation regime leads to the loss of the phase coherence and hence cooling. For this reason the FEL should operate under the saturation threshold but as close as possible. To fully utilize the electron beam cooling capacity we need to have flat longitudinal profile.

SYSTEM DESCRIPTION

The electron accelerator for the CeC proof of principle experiment [2] comprises a 112 MHZ superconducting RF gun [3, 4], two normal conducting 500 MHz buncher cavities and 20 MeV five-cell 704 MHz accelerating cavity. In order to reduce project cost the RF equipment was chosen from the available hardware and no optimization of the frequencies values was available. The design voltage of the gun cavity is 2 MV, and each copper cavity is capable of the producing 300 kV voltage.

The electrons will be generated by a multialkaline cathode, illuminated by a fiber laser with frequency doubling to 530 nm wavelength. Laser, manufactured by NuPhoton, is capable to produce 78 kHz pulses (RHIC revolution frequency) with regulated pulse width from 100 to 550 picoseconds. The rise/fall time is around 50 picoseconds. The peak power is not less 1 kW. With 1% quantum efficiency the extracted photocurrent is 4 Amperes, which is much less below of the required 80 A. Due to the low energy of electron beam we chose ballistic bunching of the beam, when compression is obtained in the drift space due to the velocity modulation. The energy chirp is eliminated in the 704 MHz cavity with slightly off-crest accelerating.

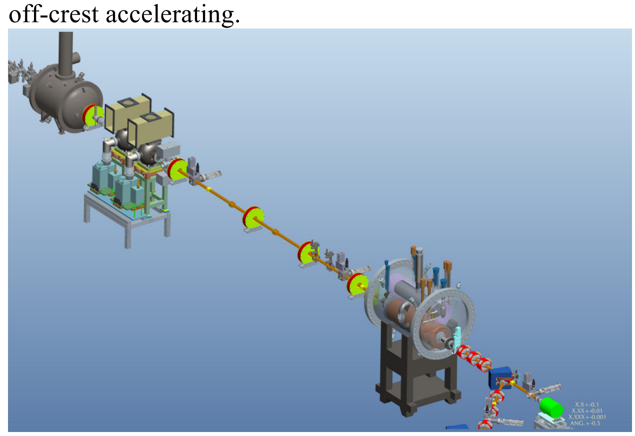

Figure 1: General layout of the electron accelerator for the coherent electron cooling proof-of-principle experiment. Electrons are generated in the 112 MH SRF gun shown in the upper-left corner, proper velocity modulation is provide by the two copper cavities, the electron bunch is compressed in the drift section and further accelerated in the superconducting 704 MHz cavity shown in the lower-right corner.

The high degree of the desired compression makes significant high order terms such as δ_{566}, which causes unevenness of compression. Such effect is well known [5, 6] and there are two approaches to overcome it. The first approach, utilized in [5], is two modulate the initial beam current and non-linear compression will provide a flat top pulse. The second approach utilizes the second order (parabolic) energy chirp, which cancels the non-linearity. We have chosen the second approach in order fully utilize the available laser power and have ability with ease adjust the pulse length. In our set-up the electron beam will be generated off-crest of the gun voltage to have the compressing chirp. The normal conducting cavities along with additional chirp will provide a parabolic compensation term.

SIMULATIONS RESULTS

The simulations were performed using code ASTRA. The initial electron beam has 2 nC charge distributed in plateau with 0.4 ns FWHM and 80 ps rise/fall time. The transverse distribution was uniform round beam with 2 mm radius and zero emittance. Total 50000 particles were generated. The gun cavity voltage was to provide 2 MeV

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electron beam (maximal field of 22.5 MV/m). The center of the beam was at -14.2° phase. The resulting longitudinal energy distribution is shown in Fig. 1.

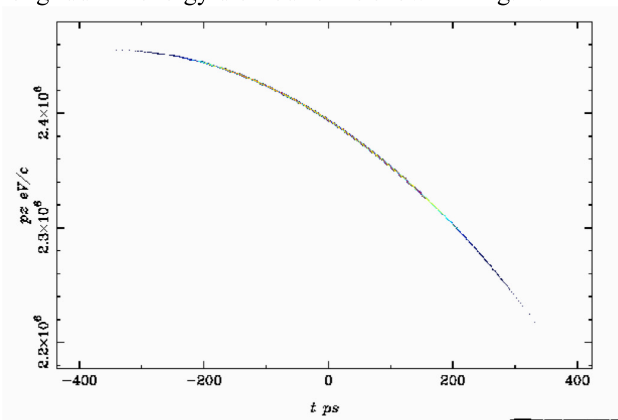


Figure 2: Distribution of the momentum along the electron bunch after the gun.

Further energy of the beam was modulated at the copper cavities with maximal field of 1.15 MV/m, which corresponds to 194 kV. The phase was -140° what allows provide both additional chirp and compensation term. The resulting energy distribution is shown in Fig. 3.

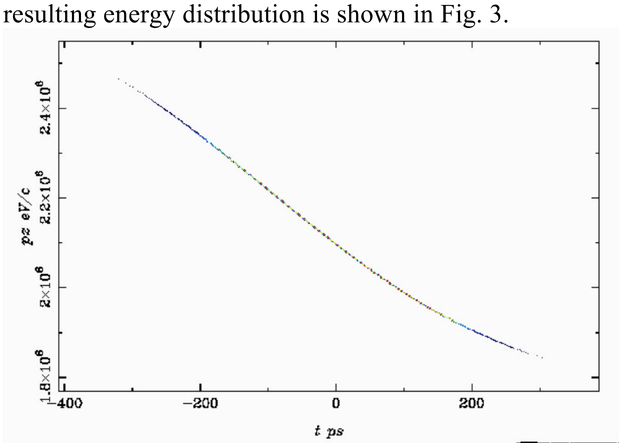


Figure 3: Distribution of the momentum along the electron bunch after the 500 MHz cavities. Note reduction of the beam energy due to the deceleration.

The resulting reduction of the r.m.s. bunch length is shown in Fig. 4.

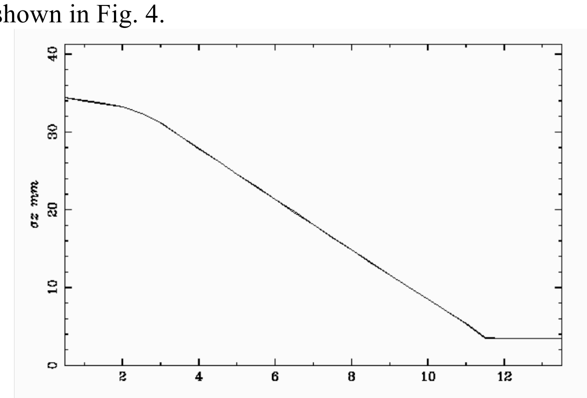
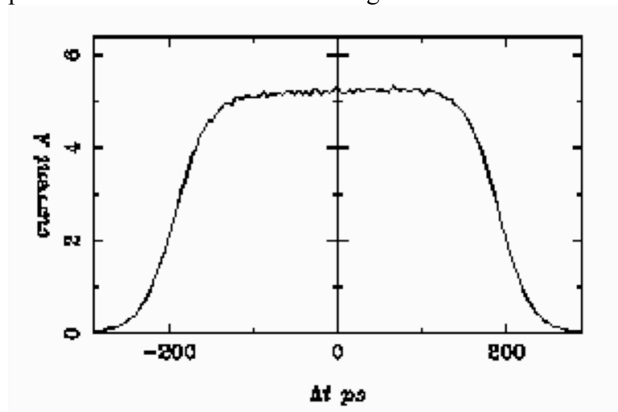
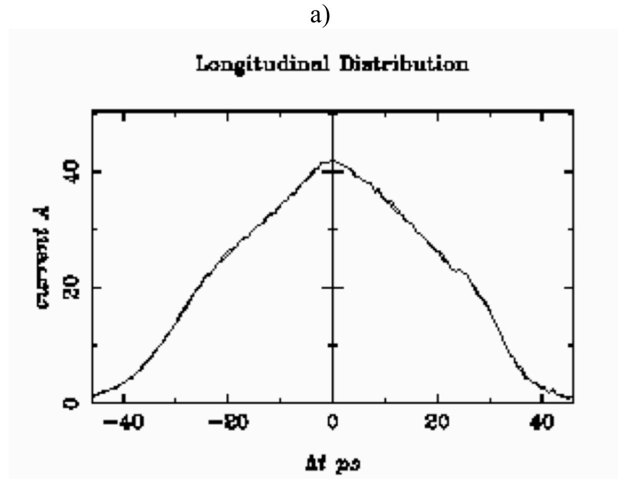


Figure 4: Reduction of the bunch length along the accelerating structure.

In the result of the velocity compression the beam profile evolves as illustrated in Fig. 5.



a)



b)

Figure 5: Longitudinal beam profiles: a) just after the gun, b) before the entrance into the 704 MHz cavity (11 meters from the cathode).

The final compression occurs inside the accelerating 704 MHz cavity where electron beam reaches minimal energy due to the fringe fields, which decelerate bunch.

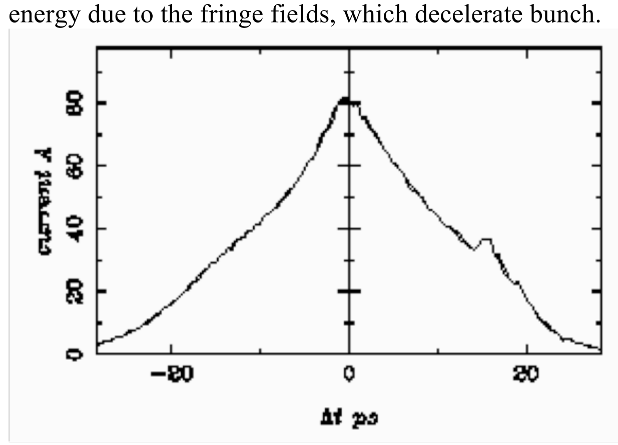


Figure 6: Final distribution of beam charge.

Flat distribution was achieved for beam without space charge but for the substantial space charge forces and

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relatively low beam energy prevented achieving the same result for a real beam.

The electron beam was injected in the 704 MHz cavity at 8.5° phase to eliminate previously introduced energy chirp. The resulting momentum distribution is shown in Fig. 7.

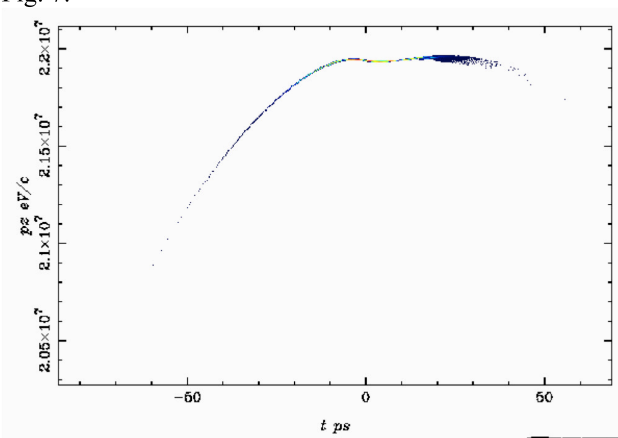

Figure 7: Momentum distribution along the electron bunch at the exit of accelerator.

CONCLUSION

The RF compensation method improved uniformity of the electron beam compression for the coherent electron cooling. Significant space charge forces prevented complete uniform beam profile achieved with relativistic beams.

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