

A TUNABLE ENERGY CHIRP CORRECTION*

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Abstract

Short (subpicosecond) pulses are central to many of the next generation light source initiatives that are based on linear accelerators. Beam compression is performed by means of a chicane utilizing a correlated linear energy chirp. A small energy chirp is kept as the beam goes through the remaining accelerating stage to compensate for wakefield effects. It is necessary to compensate the residual energy spread before the beam enters the undulator stage. We present here a concept for a passive wakefield device - chirp corrector or dechirper, to perform this compensation. We have recently demonstrated a passive energy chirp correction by self-wakefield at the Brookhaven ATF facility. In this paper we present a progress report on development of these tunable chirp correction devices.

INTRODUCTION

Free Electron Laser (FEL) operation requires a high current beam. To reach high current, typically kA – level, the electron beam is compressed. Compression is performed by a chicane, a set of four dipole magnets arranged in a + - - + pattern. For the beam to be compressed by a chicane it has to have an energy chirp, a linear correlation between the energy and longitudinal coordinate. This correlation can be obtained by running beam off-crest in the accelerating section. A natural parameter to characterize the chirp is derived from the slope: the energy difference over the longitudinal coordinate difference in MeV/mm or equivalent. For compression in chicane a positive chirp required, i.e. the head of the beam has lower energy than the tail. In this case the lower energy particles (the head) have a longer path than the high energy particles in the tail. Hence the beam is compressed as the tail catches up with the head. After the compression the beam typically has a residual chirp on the order of 40 MeV/mm [1]. Prior to injection in the undulator this chirp has to be removed as it compromises the FEL lasing. In principle, this can be done by running the bunch off-crest in the accelerating section. Alternatively a passive wakefield device can be used by utilizing the self-acting wakefield induced by the electron bunch on itself [2]. In the original proposal such

a device was called a “wakefield silencer”. Similar proposals were also put forward in [3-5]. A new name “dechirper” or “chirp corrector” was used in [5] and adopted here as a generic name for the passive wake-inducing device whose sole purpose is to remove (or create) the energy chirp. Since the impact of the dechirper linearly scales with the length of the device and the charge of the electron bunch, it is convenient to characterize the dechirper strength in units of MeV/mm/m/nC. The experimental demonstration of the idea of the dechirper was first reported in [4] where a set of dielectric lined cylindrical waveguides with different apertures were used to produce wakefields with variable strengths. Although the use of different apertures in a cylindrical geometry gives a reasonable flexibility in adjusting the dechirper strength, a continuously tunable dechirper is nevertheless preferred. This device has been tested recently and in this paper we present some recent experimental results obtained using a tunable dechirper.

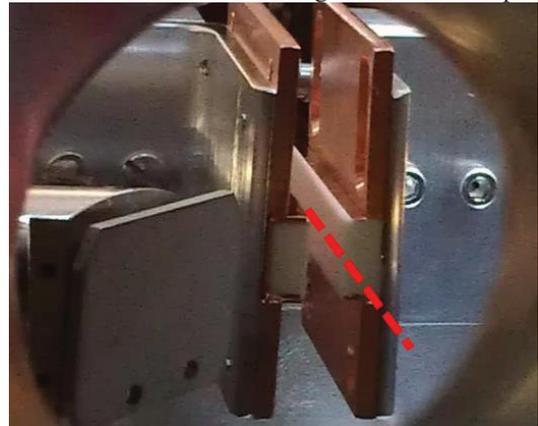


Figure 1: Tunable dechirper: two 10 cm long metallized alumina ($\epsilon=9.8$) bars, 12 mm wide and 6.35 mm thick with 1 – 6 mm variable gap.

While propagating through the dechirper each electron emits Cherenkov radiation. For a particular structure this field can be simulated and in some cases calculated theoretically [6]. Integrating over the current distribution one can get the total wakefield inside the electron bunch. For dechirper operation we are interested in the self-wakefield, the fields inside the bunch. For a linear chirp correction the self-wakefield has to be quasi-linear. This can be obtained in a number of ways, using a single mode structure or a multimode structure. Naturally, a wake

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generated by a beam can be represented by a set of modes excited in a structure. The dielectric-loaded waveguide can be made to support only one primary mode (with others having a weak coupling to the beam). This is typically done by using a thin layer of dielectric. If the wavelength of this mode is much larger than the length of the beam, then the self-wake is quasi-linear. This is obvious for a flattop beam as we convolve the constant current with the cosine wake to obtain a sine self-wake which is further approximated for short beams by a linear function of axial position. Similarly, a multimode structure would work in the case when most of the excited modes have wavelengths longer than the beam. We prefer working with a multimode structure as it is much simpler to handle in the experiment.

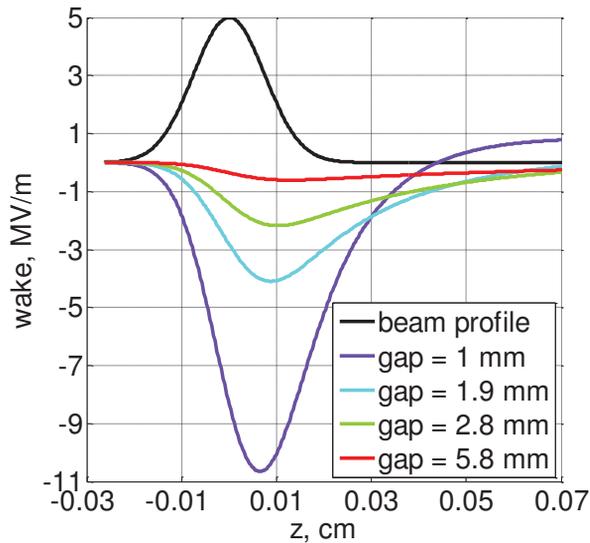


Figure 2: Principle of tunable dechirper: short range wakefields calculated for a Gaussian beam for four values of the dechirper gaps indicated on the plot. There is a linear part of the short range wake with amplitude changing as we change the dechirper gap.

The wake amplitude $\sim \eta q/a^2$, where η is the waveguide form factor, q is the charge and a is the characteristic size of the aperture. Hence tuning the transverse size of the aperture allows a corresponding adjustment of the strength of the chirp corrector (Fig. 2).

A chirp corrector also can be made using a corrugated structure [5]. Such structures typically operate as a single mode dechirpers. A multimode operation can be achieved by using deep corrugations, however, theoretical analysis in this case becomes complicated.

Defining the linear fit to the wakefield as illustrated in Fig. 3, we obtain for the dechirper strengths for a gaussian beam $S_D = 45, 87,$ and 215 MeV/mm/mnC using dechirper gaps = 2.8, 1.9 and 1 mm. It is important to point out that dechirper strength does depend on the beam distribution as illustrated in Figure 3. The self-wakefield slope differs slightly for gaussian and flattop beams.

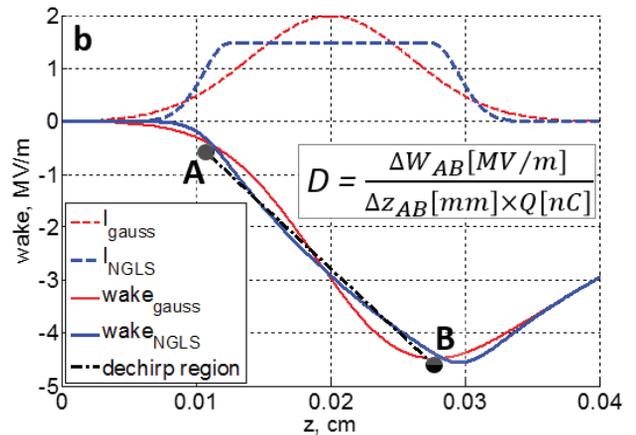


Figure 3: Illustration of the definition of the dechirper strength using the linear fit of the wakefield between points A and B (the case with a 1.9 mm dechirper gap is shown here). The red curve shows the profile of the electron charge distribution, NGLS-type 150 μ m flattop beam (not to scale).

EXPERIMENTAL RESULTS

The experimental testing of a tunable dechirper was performed at the Accelerator Test Facility in the Brookhaven National Laboratory. We by accelerating electron bunch off-crest in the linac and obtaining an energy of 60 MeV and a positive 0.33 MeV/mm energy chirp. We had a longitudinal shaping setup for the beam that was part of another experiment and produced a quasi-triangular beam, 500 μ m long with 54 pC charge. This was accomplished by a mask located at a point with a large energy dispersion between the two opposite sign dipole magnets [7]. The electron bunch length was measured with the interferometer using coherent transition radiation (CTR) from a foil located downstream of the second magnet.

The electron beam energy chirp was then manipulated by passing the electron bunch through a dechirper shown in Figure 1. After that, the electron bunch was sent into the spectrometer.

We measured the energy spread using a magnetic spectrometer. It was observed that the energy spread decreased as we closed the chirp corrector gap from 5.8 mm to 1 mm. Fig. 4 shows our experimental data: the beam is detected by a phosphor screen and imaged by a camera. On this image the horizontal dimension represents the particle energy, and the vertical dimension represents the vertical beam size. Due to the initial energy chirp one can see the correlation of the chirp value and the longitudinal projection of the beam on the spectrometer. Because the beam was quasi-triangular longitudinally and had an energy chirp, a linear correlation between the longitudinal coordinate and energy, the image on the spectrometer repeats the longitudinal beam profile, and we observe a triangular spot on the screen.

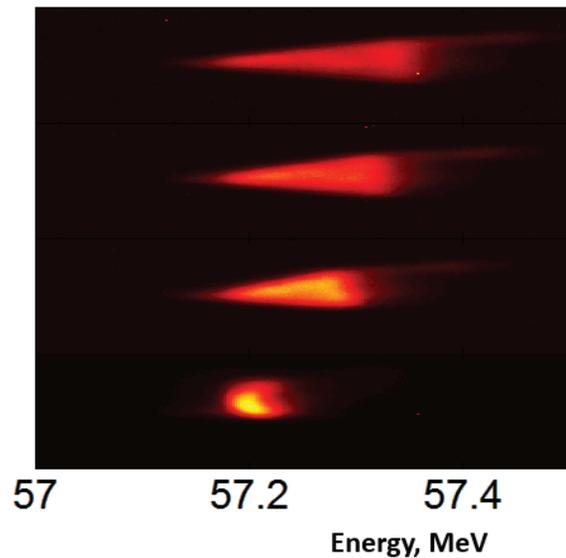


Figure 4: Experimental measurement: calibrated energy spectra of the beam passing through a chirp corrector with various gap sizes: 5.8, 2.8, 1.9 and 1 mm. The energy spread of the beam can be seen to decrease as the optimum gap size (1 mm) is approached.

When the dechirper gap was closed down to 1 mm we no longer observed any correlation and the energy spread was at a minimum. The energy chirp was calculated to be 0.33 MeV/mm (165 keV over a ~500 micron long triangular beam). This 0.33 MeV/mm was compensated in the 10 cm long dechirper. Since the total beam charge was 54 pC, the value of the dechirper strength in this case is 61 ± 6 MeV/mm/m/nC.

In summary, our work has demonstrated a tunable dechirper, a passive wakefield device for reduction of the correlated energy spread. With this device, the 0.33 MeV/mm correlated energy spread of a 60 MeV, 54 pC electron bunch at the BNL Accelerator Test Facility (ATF) was completely removed by adjusting the gap between metallized alumina bars [8] (forming a planar dielectric structure) from 5.8 mm down to 1 mm.

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