PASSIVE MOMENTUM SPREAD COMPENSATION BY A "WAKEFIELD SILENCER"*

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Abstract

We report the observation of de-chirping of a linearly chirped (in energy) electron bunch by its passage through a 5 cm long dielectric loaded waveguide structure. The experiment was conducted at the ATF facility at BNL according to a concept dubbed the "wakefield silencer" originally developed at the ANL AATF [1] which involves defining the electron bunch peak current distribution and selecting the optimal waveguide structure suitable for chirp cancellation using self-induced wake fields of the electron bunch. Our experiment has been carried out with a 247 micron triangular beam with a 200 keV energy spread that was reduced by a factor of three to approximately 70 keV by passing it through a 0.95 THz dielectric-lined structure. Theoretical analysis supports the experimental results. Further exploration and applications of this technique will be discussed as well.

INTRODUCTION

The free electron laser (FEL) is considered to be the main candidate for a short wavelength (UV to X-ray), short pulse (femto- to attosecond) light source. Demands on the electron beam needed to drive this class of FELs have become more and more challenging, including high repetition rate (~MHz), high peak current (a few kA), and low emittance (sub-micron normalized emittance) [2].

Short pulses (subpicosecond) are central to many of the next generation light source initiatives that are typical of modern linear accelerators. At the same time, at the output of the last compressor the electron beam will be left with a small chirp to compensate for wakefield effects through the rest of the accelerating stages [3, 4]. Although relatively small, this energy spread needs to be compensated using a specially designed device.

The use of a Cherenkov dielectric wakefield compensation scheme ("silencer") to correct the correlated energy distribution (chirp) of a short, low emittance electron bunch was originally suggested in references [1, 5]. This technology using an adjustable dielectric compensating structure can be applied to a soft X-ray FEL SRF linac.

Removing the chirp of a beam can be useful in many other situations, in particular wakefield acceleration experiments. In these experiments a high charge "drive" beam passes through a wakefield structure and generates a wake behind it. A "witness" beam follows behind the "drive" and is accelerated or decelerated in the wake of the drive beam depending on its timing with respect to the drive beam. If the drive beam has large energy spread (for example resulting from bunch compression [6] or from the mechanism of "drive" – "witness" beam formation [7]) and the wakefield structure is not very long, the energy of the witness beam can be insufficiently large to distinguish it from the drive beam on the spectrometer. If we are able to remove the correlated energy spread from the drive beam this measurement becomes possible.

We study dielectric loaded accelerating structures as chirp compensating devices. Standard iris-loaded structures could be used as well [8]. A planar chirp compensating structure can be made tunable via an adjustable aperture to accommodate various scenarios for beam chirp at the accelerator facility.

In this paper we will present theoretical studies, experimental results from Accelerator Test Facility (ATF) of Brookhaven National Laboratory (BNL) and our future plans.

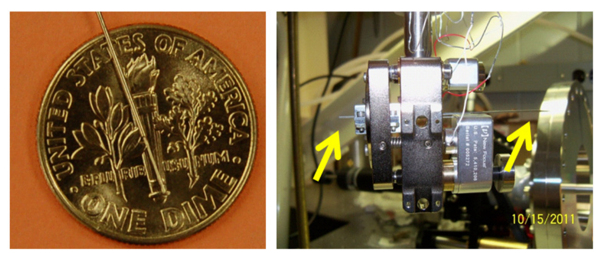

Figure 1: Left: photo of a quartz tube in a stainless steel jacket, used in the experiment. Right: photo of a motorized positioning holder with tube (yellow arrows) inserted.

EXPERIMENT AT THE ATF (BNL)

In this experiment [9] a 57 MeV beam passes through a 1 inch long quartz tube with ID = 330, OD = 390 μm, metallized on the outside by gold sputtering and inserted into a stainless steel tube housing. At the ATF differently shaped subpicosecond beams can be produced by the technique described in [7]. A beam accelerated off-crest in the linac and hence having a linearly correlated energy chirp (in our case with the *head of the beam having lower energy than the tail*) passes through a dogleg – a dispersionless translating beamline section that consists of two dipoles whose bend angles are equal in magnitude but opposite in sign. Focusing optics are located between the dipoles. A mask is placed between the dogleg dipoles

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where the beam transverse size is dominated by the correlated energy spread. After the second dipole magnet the transverse pattern introduced by the mask becomes the longitudinal charge density distribution. In our case the mask was motorized and allowed creation of triangular beams of various lengths. All of these beams have a linear energy chirp due to the shaping method used [7]. The goal of the experiment is to demonstrate the chirp correction.

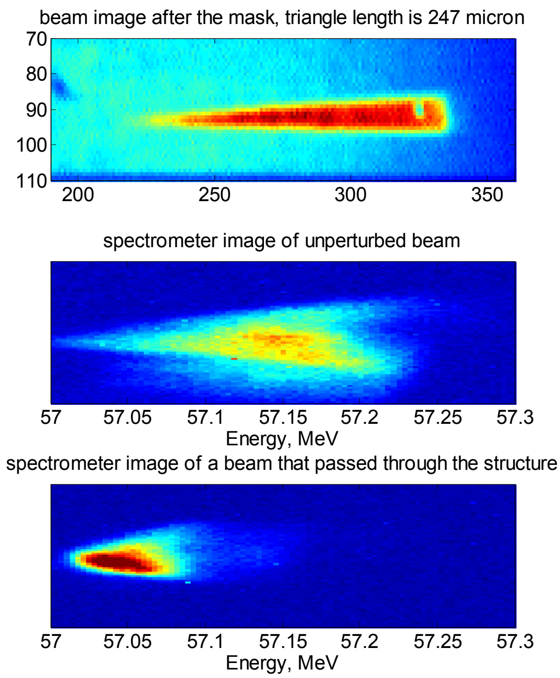

Figure 2: Top: image of the beam right after the mask. Middle: spectrometer image of the beam downstream without chirp corrector in place. Bottom: spectrometer image of the beam passed through the chirp corrector.

There is a one to one correspondence between the mask pattern (Fig. 2, top) and the beam's longitudinal distribution after the second dipole magnet. Therefore with proper calibration the image of the beam directly after the mask represents the longitudinal beam distribution. This calibration is done via coherent transition radiation (CTR) interferometry. In this technique two test beamlets are created by the mask and recorded on a phosphor screen after the mask. In particular the distance between the beamlets is measured on the phosphor screen. Then after the second dipole the distance (along z) between these two beamlets is measured by interferometric manipulation of the transition radiation signal which the beamlets emit passing through a thin CTR foil. Wavelengths longer than the beams are emitted coherently and carry information about the bunch lengths [10, 11]. Transition radiation is sent to an interferometer and the signal is recorded by a helium-cooled bolometer [7, 12]. From this measurement the distance between beamlets was determined and the phosphor screen image was calibrated. In this case we neglected the dispersion of the beam while it was being delivered to the experimental area where the chirp correction structure was installed. The dispersion effect was estimated by simulation (using the program MAD (Methodical Accelerator Design) [13]) to be less than 5%. That is why the beam delivered to the spectrometer screen maintains its triangular shape fairly well.

In the case depicted in Fig. 2 and 3 we used a 247 micron triangular beam with a 200 keV energy spread (FWHM) which was reduced (Fig. 2 middle vs bottom, Fig. 3a) by almost a factor of three to 70 keV (the spectrometer resolution limit!) by passing it through the structure. We developed a simulation tool for energy chirp correction structure design. Figure 3 shows the successful benchmarking of the code (b, c, d) with the experimental results (a).

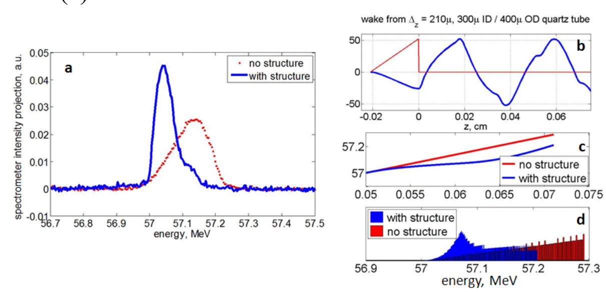

Figure 3: a) measured and calibrated spectrometer projection comparison of original beam energy spread vs. compensated energy spread; b) – d) simulation results: b) wakefield generated by the triangular beam; c) energy vs longitudinal coordinate comparison of original beam (linear chirp) vs compensated beam; d) energy histogram: original beam vs energy compensated beam.

In principle, by choosing a smaller size triangle one can reduce the energy spread even further. However the spectrometer resolution limit (65 keV FWHM) prevented us from observing any narrower energy spreads in this experiment.

CHIRP COMPENSATION AT FACET

We are considering the possibility of reducing the energy spread at Facility for Advanced Accelerator Experimental Tests (FACET) at Stanford Linear Accelerator Center (SLAC) by means of a passive wakefield structure.

Wakefield silencing [1] can be used to reduce the nearly 1 GeV energy spread of the FACET beam [6]. Considering the small dimensions of the FACET beam (σ_z = 30 μm) any E-201 collaboration structure proposed for FACET studies [14] can be used as a silencer (since the beam is smaller than any reasonable structure wavelength). In this example we consider a σ_z = 30 μm FACET beam passing through the quartz tube with ID = 300 μm, and OD = 400 μm. This beam will produce an impressive 1.5 GV/m/nC self-decelerating field (Fig. 4, left) and after about 21 cm the energy chirp is reduced to just 20% of the original spread (Fig. 4, right).

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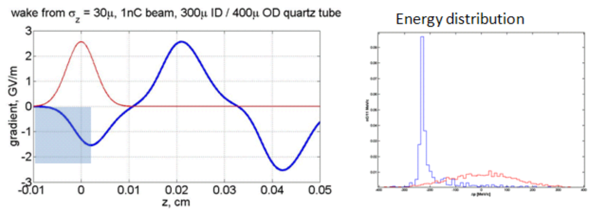

Figure 4: Left: longitudinal wakefield of a 30 µm gaussian bunch in a FACET silencer structure; Right: simulated FACET spectra with (blue) and without (red) silencer.

In the simulation we assumed that the FACET beam energy chirp is mostly linear. In reality the energy – longitudinal coordinate correlation is non-linear [6]. Several wakefield compensating structures with various frequencies / apertures may be used to compensate a non-linear energy chirp.

TUNABLE CHIRP CORRECTOR

For effective energy compensating system a tunable (over a reasonable range) chirp correction structure is required to accommodate possible charge and chirp changes in different operating regimes. We are developing a design of such structure (Fig. 5) and plan to test it at the ATF as well as at FACET.

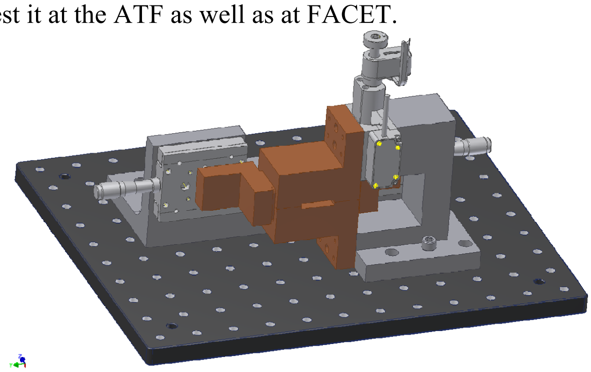

Figure 5: Preliminary design of a tunable energy chirp compensating structure: slab symmetrical dielectric loaded accelerating structure with adjustable aperture.

For a tunable energy compensating structure we plan to use a rectangular structure (slab symmetric) with an adjustable beam aperture height (200 – 400 micron) and fixed dielectric thickness – 40 micron (alumina). The width of the beam gap is 1 mm. This structure is similar to the diamond structure we developed for a previous ATF experiment [9]. Dimensions are chosen for reasonable ease in handling. When the aperture of the structure is changed (enlarged from 200 to 400 µm) the frequency of the structure decreases from 0.514 THz down to 0.45 THz. For a 245 micron triangular bunch (40 pC) (the same used in our previous experiments at the ATF and shorter than the structure's fundamental wavelength) the wake profile inside the beam does not change much except for the decelerating field strength that spans the range from 9 to 20 MV/m. For a fixed structure length (~ 1 inch) this allows tuning of the energy compensation for differently chirped beams.

SUMMARY

We demonstrated energy chirp compensation successfully in an experiment at the ATF (BNL). We studied various scenarios and have proposed further experiments at ATF and at FACET (SLAC). We are designing a tunable chirp corrector to accommodate possible charge and energy chirp changes in different operating regimes. We are studying multi corrector systems to be able to compensate non-linear energy chirps.

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