GENERATION AND CHARACTERIZATION OF MICROBUNCHED BEAMS WITH A WIRE MESH MASK

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Abstract

We use a wire mesh mask placed in a dispersive region of the Accelerator Test Facility (ATF) at Brookhaven National Laboratory to produce a train of picosecond microbunches. The bunch spacing and charge can be tailored for specific applications. We plan on using this method to generate a train of drive bunches and a witness bunch for plasma wakefield accelerator experiments.

INTRODUCTION

Plasma-based accelerators, such as the plasma wakefield accelerator (PWFA), and beam-based radiation sources or free electron lasers (FELs) have made tremendous progress in a past few years. Manipulation of the beam longitudinal phase-space can often lead to great improvements in the device's performance. For example, pre-bunching the beam at the appropriate wavelength can significantly reduce the gain length of an infrared FEL [1]. Driving a plasma with a train of bunches can increase both the accelerating gradient [2, 3] and the transformer ratio and therefore the energy transfer efficiency of a PWFA [4]. These applications require bunch trains with a periodicity of the order of the device wavelength, i.e., one bunch per bucket.

Trains of bunches with picosecond or femtosecond length and spacing are therefore of great interest. We present here preliminary results of a proof-of-principle experiment using a wire mesh mask to produce a train of picosecond bunches.

A number of methods have been proposed to produce a train of microbunches. One of them consists of sending a train of closely spaced UV laser pulses onto the photocathode of a rf electron gun [5]. The method we use consists of placing a mask in a dispersive region of the beam line to intercept part of the bunch charge. We use a simple wire mesh mask to demonstrate that a bunch train can be produced. The advantage of the mask is that it can be designed to produce a train with variable bunch length and spacing, and can therefore be tailored for specific applications.

This method can be used in all beam lines that include a magnetic chicane or a magnetic dogleg.

ATF BEAM LINE

At the ATF, the electron beam is produced in a 1.6 cell, S-band rf-photoinjector [6] and is followed by a 70 MeV S-band linac. The electron bunch with a normalized emittance of ≈2 mm-mrad and ≈350 pC can be sent to three different beam lines. For the present experiment, the beam is directed to ATF Beam Line #2 using two dipoles and five quadrupoles arranged in a dogleg.

For the present application the beam energy is E_0 = 50 MeV and the dogleg quadrupoles are adjusted to obtain a region of large dispersion and low beta function (in the plane of dispersion). The beam is also accelerated off the crest of the rf wave in order to impart a correlated energy spread on the bunch (typically $\Delta E/E_0 \approx \pm1.5\%$). The beam line includes a limiting slit aperture located at a point in the dogleg where the dispersion is $\eta\approx-0.5$ m. This slit can be used to limit the energy spectrum of the bunch. After exiting the dogleg, the beam propagates over a dispersion-free distance of 6.5 m before entering a magnetic spectrometer with a final dispersion of η = 1 m. Before the dogleg, the bunch is about 1500 μm-long (or ≈5 ps, full width). The dogleg longitudinal dispersion function R_{56} is ≈+4 cm, which means that the effect of the dogleg is to either compress or stretch the bunch by ±400 μm (or ±1.3 ps, depending on the sign of the energy chirp) per percent of correlated energy spread.

WIRE MESH MASK

In this proof-of-principle experiment we use a simple wire mesh mask to demonstrate that a bunch train can be produced. The mask is made of 500 μm diameter tungsten wires stretched on a metallic frame with a uniform distance between the wires (periodicity) of D = 1270 μm. A picture of the mask is shown in Fig. 1. When placed at normal incidence with respect to the electron beam, the mask transparency is therefore (1270-500)/1270)=61%. This shows the main drawback of the method. The charge that strikes the wires will be lost along the beam line because of both the energy loss and emittance growth it suffers in the wires. The mask can be angled with respect to the beam direction to vary the mesh periodicity, but at the expense of the transmitted charge. The mask can be used in conjunction with the beam line energy slit to control the number of microbunches in the train.

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Figure 1: Picture of the wire mesh mask and frame. The tungsten wires are horizontal in the picture. The wires are 500 μm in diameter with a period of 1270 μm.

BUNCH TRAIN GENERATION

The wire mesh mask is placed in the dogleg that is used to deliver the beam to the various ATF beam line. For this application, the dogleg quadrupoles are adjusted to produce a region with large x-dispersion and small beta-x function. The small beta function is necessary for the mask to cleanly modulate the bunch charge. The bunch with a correlated energy spread (E, t) acquires a correlation between x-position and energy, i.e., between x-position and time (x, t) in the dogleg. The mask with the wires axis perpendicular to the x-z casts a shadow in the x-plane. The number of microbunches produced depends on the bunch relative energy spread $\Delta E/E_0$, beam line dispersion at the mask η, and wire mesh periodicity: $N \approx \eta(\Delta E/E_0)/D$. Figure 2 shows an image of the bunch on a screen placed a short distance downstream from the mask. The shadow of the mask is clearly visible. In this case, the number of bunches is six. Note that the bunch spacing is not constant. This is probably due to a nonlinear incoming energy chirp. This nonlinearity is produced when the beam in the accelerator is at a relative phase where the curvature of the accelerating field along the bunch is too large. The variation in microbunch charge reflects the charge distribution of the incoming bunch.

After the second dipole magnet of the dogleg that dispersion is brought back to zero, and the (x,t) correlation returned to an (E, t), correlation. That means that the mask pattern is converted from a spatial one to a temporal one. In the process the bunch length may change according to the sign of the energy chirp, as explained earlier. To prove that the space to time conversion occurred, we used coherent transition radiation (CTR) interferometry. Transition radiation (TR) is emitted when a relativistic particle crosses the boundary between two media with different dielectric constants. In the case of a vacuum to metal boundary, TR has an extremely broad spectrum that ranges from the plasma frequency of the metal to zero frequency [7]. For an ensemble of charges, the TR is coherent for wavelengths longer than that of the bunch, and carries information about the bunch length and time structure. Sending the TR into a Martin Puplett interferometer with a variable delay arm produces an autocorrelation of the signal from which bunch length and spacing can in principle be retrieved. However, wavelength filtering effects along the CTR transport or by the detector may lead to distortions of the autocorelation signal [8].

Picosecond long bunches emit CTR wavelength in the THz range (>300 μm wavelengths). We use a liquid helium-cooled silicon bolometer detector. The backward CTR produced by the bunch train exits the beam line through a high-density polyethylene (HDPE) window and is focused onto the detector using an off-axis parabola.

Preliminary autocorrelation results show that the spatial mask pattern is transferred into a temporal pattern. The measured bunch spacing is of the order of 350 μm. The number of bunches can be chosen by varying the width of the beam line energy slit. Detailed results will be published elsewhere [9].

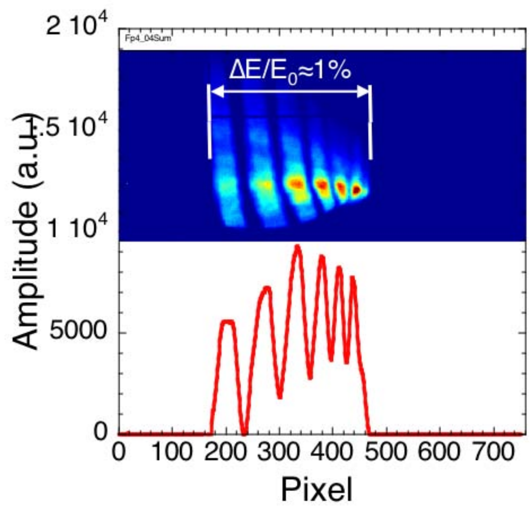

Figure 2: Picture of the beam downstream from the mask, but still in the dogleg, and summed image profile showing the mask pattern imprinted upon the beam.

SUMMARY

Preliminary experimental results show that a mask placed in a dispersive region of a beam line can be used to produce a temporal train of picosecond microbunches. The number of microbunches can be varied by using a slit in conjunction with the mask. The mask can be designed to form a train pattern for specific applications. We plan on producing a train of drive bunches followed by a witness bunch for PWFA studies at the ATF.

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