Z-SLICER: A SCHEME FOR SHAPING THE ELECTRON BEAM PROFILE IN A LINAC*

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Abstract

A train of short bunches (∼100 fs) are at a premium at accelerator facilities and their applications include tera-hertz (THz) generation, short bunch diagnostics, advanced accelerator R&D, etc [1].In this work we report on the design and simulation of an experiment involving a 20 MeV electron beam, that will be intercepted by a set of metallic slits inside a bunch compressor. After the mask, some electrons are scattered while other pass through un-affected. After exiting the bunch compressor, those electrons that were not affected by the slits will appear as short electron bunches. The key advantage of our scheme is its simplicity, tunability and low cost. The scheme does not require any additional hardware such as lasers, undulator, or transverse deflecting cavity. The tuning variable is only the RF-chirp. The detection of the bunching requires just a skew quad in the chicane and a transverse screen downstream.

INTRODUCTION

Among the various techniques available to generate short or modulated bunches for THz radiation generation at low energies[2, 3, 4, 5, 6], one simple way is to use a metallic-slit mask inside a dispersive section[7, 8]. In this paper, we describe Z-Slicer, a tool that is planned for installation at the Advanced Superconducting Test Accelerator (ASTA) low energy bunch compressor, which has the flexibility to generate a train of short pulses, a train of pulses of varying separation or just a slice of a bunch.

THE ASTA LINAC

The ASTA linac will employ a Cs2Te photocathode irradiated by an ultraviolet (264 nm) laser pulse of rms width 3.2 ps, producing bunch trains at a repetition rate of 5 Hz and a train frequency of 3 MHz for a 1 ms macro-pulse. The number of bunches in each train can be anywhere from 1-3000, depending on the beam charge and permit. The charge of each bunch can range from 20 pC to 3.2 nC giving an average current of 9 mA at maximum charge. The low energy beamline can have energies ranging from 20 MeV to 50 MeV.

* Fermi Research Alliance, LLC operates Fermilab under contract No. DE-AC02-07CH11359 with the U.S. Department of Energy

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Z-SLICER INSIDE THE ASTA BUNCH COMPRESSOR

The ASTA bunch compressor is a chicane style bunch compressor with the parameters listed in Table 1. The Z-Slicer will be installed at the center of the ASTA chicane. The Z-Slicer tool consists of a stepper motor controlled actuator (rotatory stage) along with a 316L stainless steel holder that has three positions. The first position can hold four blades, the second one a YAG screen with a mirror for a spot size measurement, and the final is an impedance matching cage for the beam to pass through. The bunch compressor is equipped with a skew quad just before the third dipole that allows time-dependent studies of CSR or measuring the formation of the train of pulses without resorting to radiation based detection systems, such as a streak camera, bolometer or an interferometer. The ASTA bunch compressor also has a complete plan for collection of CSR/CER for beam diagnostics and THz-based instrumentation. The ASTA bunch compressor is built and ready for commissioning with the low energy beam. A schematic of the ASTA buch compressor and the operation of the Z-Slicer is shown in Fig. 1.

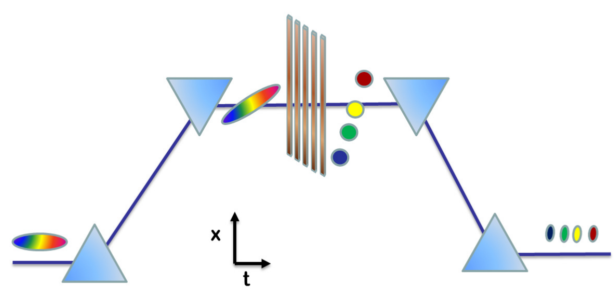

Figure 1: Schematic of the ASTA bunch compressor with the Z-Slicer.

THEORY OF OPERATION

The energy-chirped beam generated from the photoinjector after passing through the accelerating cavity is then sent to the bunch compressor. At the center of the bunch compressor, the bunch is intercepted by a slit mask which selectively scatters some of the electrons while other electrons are transmitted through the rest of the chicane. At the end of the chicane, such transversely separated beamlets are transformed into a train of short bunches longitu-

Table 1: Bunch and compressor parameters

Parameter	Value	Units
Beam energy	50	MeV
Initial bunch length	0.8	mm
Slit spacing (center to center)	1	mm
Slit width	50	μm
Dipole bending radius	0.958	m
Dipole length (steel)	0.301	m
Dipole angle	18	degrees
R_{56}	-18	cm
η	-30	cm

dinally. The spacing between the bunches and the length of each bunch is determined by several factors such as the dispersion of the chicane , the transverse betatron spot size of the beam at the mask, the width of the slit mask , the uncorrelated relative beam energy spread and the RF-energy chirp (h) on the beam . The formula that relates the length of the bunch at the exit of chicane to the width of the slit is given by $\sigma_z = \frac{1}{|\eta h|}\sqrt{\eta^2\sigma_u^2 + (1+hR_{56})^2[\Delta X^2 + \varepsilon\beta]}$, where σ_z is the output bunch length, R_{56} is the longitudinal dispersion of the chicane, $\Delta X = \frac{w}{2\sqrt{3}}$ is the rms width of the mask, ε is the natural beam emittance, and β is the betatron function at the mask[9]. It can be seen that when hR_{56} is large, the output bunch profile follows the mask profile (ΔX). This can be done by making $|1 + hR_{56}| >> 1$. For a chicane in our convention $R_{56} < 0$ ($z > 0$ corresponds to the tail) , therefore by setting $h < 0$ (operating on the falling slope of the RF accelerating cavity), the output bunch profile can be made to follow the mask profile. This technique is limited by the initial slice energy spread and emittance of the beam.

Z-SLICER BLADES

The Z-Slicer blades were manufactured by Oxford lasers Inc. using precision laser-machining on a tungsten sheet of thickness 500 μm. The SEM images of two of the four blades are shown in the Fig. 2 and Fig. 3.

THERMAL ANALYSIS

A thorough thermal and stress analysis has been done for the Z-Slicer with one mm thick tungsten (a conservative estimate while in practice we used a 0.5 mm thick tungsten). Assuming only radiative cooling and a beam intensity of 1.25E13 electrons per macro-pulse, peak temperatures are below 2000 K, and should be within the capability of tungsten. Stresses approach the 100 MPa elevated-temperature ultimate strength of tungsten, and cyclic fatigue stresses may warrant further evaluation. However, these analyses assume worst-case conditions; the actual implementation, beam and operation parameters may be less aggressive. A steady state thermal analysis is shown in the Fig. 4. A transient analysis shows the peak thermal cycling is 310 K at

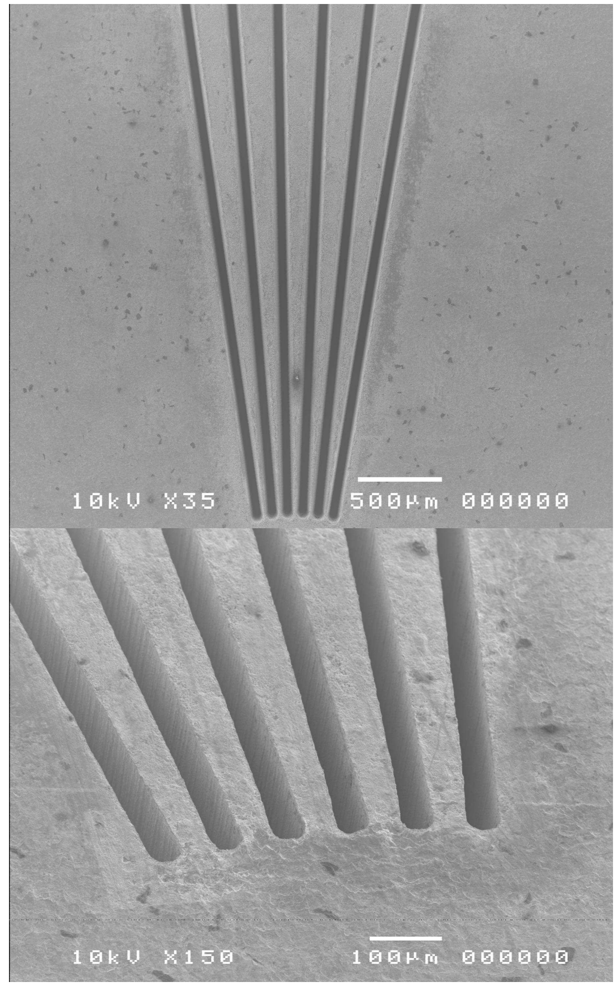

Figure 2: SEM images of the multi-V slits (top) showing the change of the distance between the slits as a function of transverse position. The bottom SEM image is on the exit side of the slits showing the topography.

the center of the mask. At the edges of the mask, there is no discernable cyclic response. The 1ms duration of the macro-pulse is so short that no significant heat transfer occurs within the pulse. As such, the magnitude of this temperature jump is determined by the energy deposition and the specific heat capacity of the tungsten material.The peak temperature of 1985 K is within the inherent capability of tungsten. Though the melting point of tungsten is quite high, the practical limit in this application may be the rate of vaporization. This rate is low ($<\sim$3E-12 g/cm2/s) at T $<$ 2200 K[10].

PULSE TRAIN DETECTION USING SKEW QUAD

When a linearly chirped beam is transversely dispersed in the bend-plane (typically x), a skew quad at the highest dispersion point (at the center of the chicane) couples x with y (and therefore y with time) that can then be transferred to the y-plane downstream through R_{34}. There-

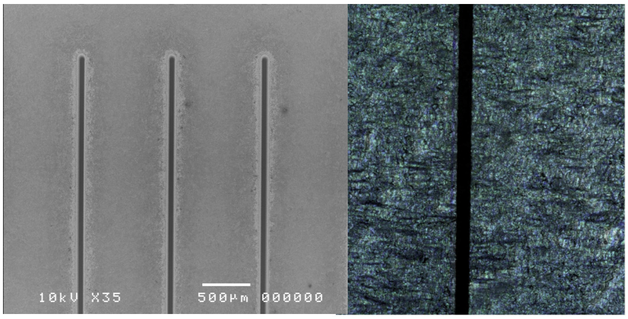

Figure 3: The SEM image of a standard multi-slit (left) with the Laser Scanned Microscope image (right). The LSM measurement yields 47.4 μm as the width of the slits .

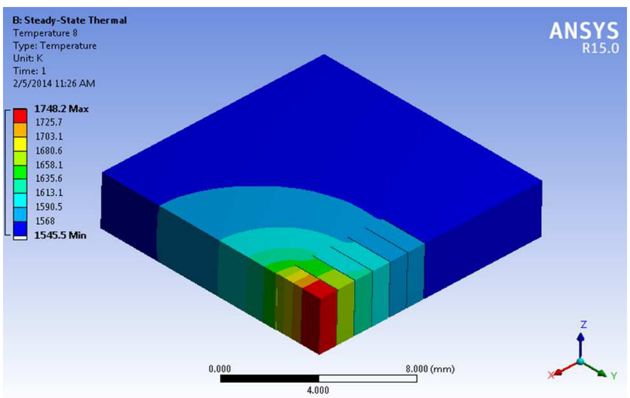

Figure 4: Steady state thermal analysis of the quarter of the slit-maks assuming the beam is hitting the center of the slits.

fore while the x-dispersion returns to zero as in an achromatic lattice like chicane, the y-dispersion is leaked giving a way to measure the time profile using a transverse profile monitor. Utilizing a YAG/OTR screen, as shown in Fig. 5, is a fast and inexpensive way to detect bunching when compared to radiation-based detection systems that require bolometers, charge-sensitive interferometers, or a transverse deflecting cavity.

CONCLUSION AND FUTURE WORK

Currently, the Z-Slicer blades have been manufactured and holder is being designed. The Z-Slicer supports a wide range of bunch spacing and bunch shapes. Both the process and design are scalable to accommodate user requirements that might arise in the future, e.g. any shaped blades can be designed and fitted into the holder. Initial tests are planned to be done with a 20 MeV beam.

ACKNOWLEDGMENTS

The authors of this paper would like to acknowledge those working to make ASTA a reality, especially colleagues in the SRF Electron Linac Department, Accelerator and Technical Divisions, and Fermilab management.

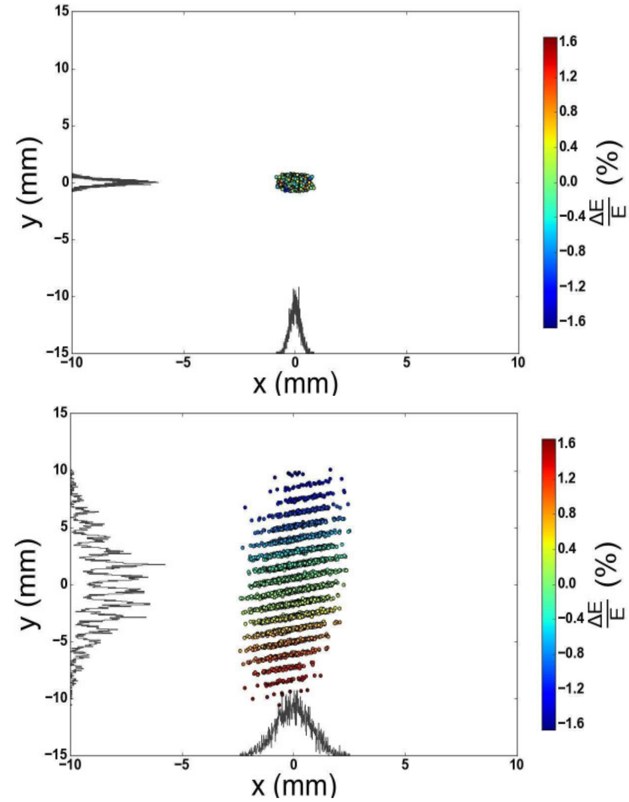

Figure 5: The transverse profile of the electron beam with the slits inside the beamline. The upper figure is the image on the transverse profile monitor YAG/OTR when the skew quadrupole is turned off and the lower figure when the skew quadrupole is turned on. The skew quad in effect functions like an RF deflector albeit imperfect

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