ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW089

TUNABLE BUNCH TRAIN GENERATION USING EMITTANCE EXCHANGE BEAMLINE WITH TRANSVERSE WIGGLER

Gwanghui Ha, Manoel Conde, Jiahang Shao, John Power, Eric Wisniewski,
Argonne National Laboratory, Lemont, USA

Abstract

The emittance exchange (EEX) beamline provides a correlation between the upstream transverse momentum and downstream longitudinal position. This property can be used to convert a transverse momentum modulation on the bunch upstream of EEX into a temporal modulation on the bunch after the beamline. This method is similar to using a chicane to convert an upstream energy modulation into a bunch train after. The transverse momentum modulation is given to the bunch with an alternating magnet array (i.e. a wiggler rotated by 90 degrees). The EEX method can be used to control both the microbunch length and the spacing between the microbunches. This enables independent control of the radiation frequency and its bandwidth. Progress on this new method and plans to demonstrate it at Argonne Wakefield Accelerator (AWA) facility are presented.

BUNCH TRAIN FROM TRANSVERSE MODULATION

One of the best known methods of generating a bunch train is done with a chicane. The energy modulation on a bunch upstream of the chicane is converted, via the R56 of a chicane, into a density modulation on the downstream bunch [1,2]. The energy modulation introduces multiple negative longitudinal chirps along the bunch and it becomes compressed micro-bunches via the chicane. Although this method is a good way of generating a high quality bunch train, it cannot control the bunch train properties independently: micro-bunch length and bunch separation. The upstream beam's macro longitudinal chirp and energy modulation amplitude determine the micro-bunch length. The control of these parameters requires major change on the beamline such as linac phase control, wiggler gap control etc. The R56 of the chicane and the macro longitudinal chirp determine the bunch separation. The R56 of the chicane is not easy to change since it requires a change of the bending angle.

In this paper, we introduce an alternative bunch train generation that is potentially simpler and more flexible. The method uses a transverse wiggler and an emittance exchange (EEX) beamline to replace the energy modulator and the chicane, respectively. In the first step, a transverse wiggler imparts a sinusoidal modulation of the beam's transverse angle (x') and a short drift converts it into a density modulation (x) of the transverse space (see Fig. 1). In the second step, an EEX beamline transforms this transverse density modulation into a longitudinal density modulation (or current distribution) [3,4].

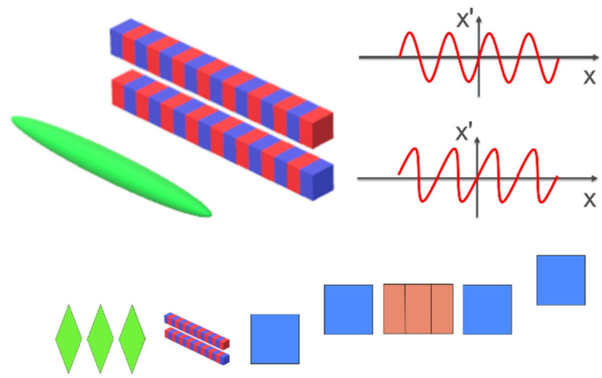

Figure 1: Conceptual drawing of the angle modulation. A transverse wiggler imparts a sinusoidal modulation of the transverse angle (x') and a subsequent short drift converts this into a transverse density modulation (x). Modulation conversion to the longitudinal density modulation is done by an EEX beamline followed by the transverse wiggler. Quadrupole magnets are usually required to make the bunch pass through the wiggler and control the macro-slope of transverse phase space.

Let us assume that the transverse angle modulation imparted by the transverse wiggler can be expressed as,

$$\Delta x' = A \sin\frac{2\pi}{\lambda_w} x, \tag{1}$$

where A is the modulation amplitude determined by the transverse wiggler and λ_w is the wiggler period. Then, the final current profile after the EEX beamline can be expressed as,

$$\frac{N(z)}{N_0} = 1 + \sum_{n=1}^{\infty} b_n \cos\frac{2n\pi}{\kappa\xi\lambda_u} z, \tag{2}$$

where κ is the kick strength of the deflecting cavity in the EEX beamline and ξ is R56 of the dogleg in the EEX beamline. b_n is the bunching factor and can be written as,

$$b_n = 2J_n\left(\frac{2n\pi}{\lambda_u} AB\right) \exp\left[-\frac{1}{2}\left\{\frac{2n\pi}{\lambda_u}\sigma_{x'}B\right\}^2\right], \tag{3}$$

where B is $\frac{1}{\kappa^2\xi} - \bar{L}$, and $\bar{L}$ is traveling distance term of the EEX beamline. The result above is in the same analogy for Ref. [1].

Since Eq. (2) started from a uniform horizontal profile, the final current profile without modulation (A=0) becomes a uniform profile. However, a non-zero A starts to introduce a density modulation as shown in Fig. 2. When

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW089

A=1.27E-3, the EEX beamline reaches critical bunching of the micro-bunches and produces extremely sharp spikes (orange-solid curve). When A is smaller than critical bunching condition, the micro-bunches are under-compressed and the micro-bunch length is increased which causes peaks to overlap (see blue curve). On the other hand, when A is larger than the critical condition we start to see double peaks due to the folded sinusoidal peaks. Therefore, we can control the train distribution by controlling A which can be easily accomplished by adjusting the gap of a small transverse wiggler.

For the current design, the required magnetic field for critical bunching is ~0.04 T. The transverse wiggler for this weak magnetic field has the physical dimension of 5 cm wide, less than 1 cm long with less than 1 cm gap.

This paper does not describe a method of separation controllability using the EEX beamline since it can be found in several publications related to EEX-based bunch compression [5-7].

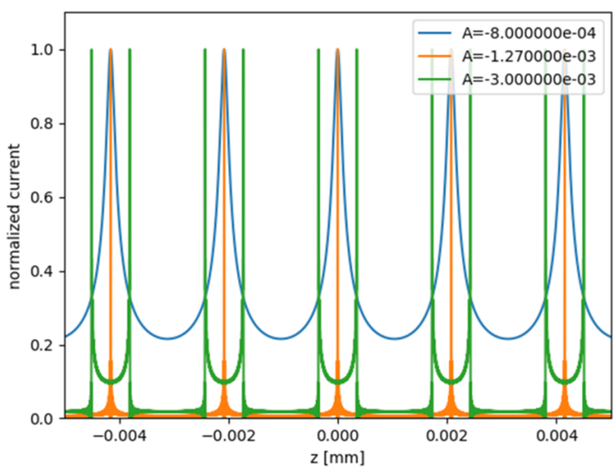

Figure 2: Estimated current profile after the EEX beamline with given transverse modulation amplitude A.

START-TO-END SIMULATION

We now demonstrate the concept described in the previous section with start-to-end simulations using the particle tracking simulation code GPT [8] for the Argonne Wakefield Accelerator facility [9].

To generate a uniform charge balance between micro-bunches, it is important to imprint the modulation on a uniform transverse profile. This can be accomplished by the MLA proposed in Ref. [10]. This optical element can homogenize the UV laser from Fig. 3a to Fig. 3b. The shape of the homogenized UV is determined by the shape of the micro-lens. This uniform-rectangle UV generates the same electron beam profile, and it can be easily imaged to the entrance to the EEX+wiggler system.

Figure 4 shows the GPT simulation result. The uniform-rectangle electron beam generated by the MLA is imaged to the entrance of the transverse wiggler as shown in (a). A transverse wiggler imparts the modulation as (b) whose modulation period is 6.4 mm. Here the horizontal phase space has a linear slope due to the focusing coming from the quadrupole (not shown) in front of the wiggler. Since the wiggler does not change the longitudinal phase space, the longitudinal phase space after the wiggler stays in its typical shape (c). The EEX beamline exchanges the horizontal and longitudinal phase spaces, and the simulation shows the longitudinal phase space has a clear modulation as shown in (d). Also, the modulation is converted to the density modulation.

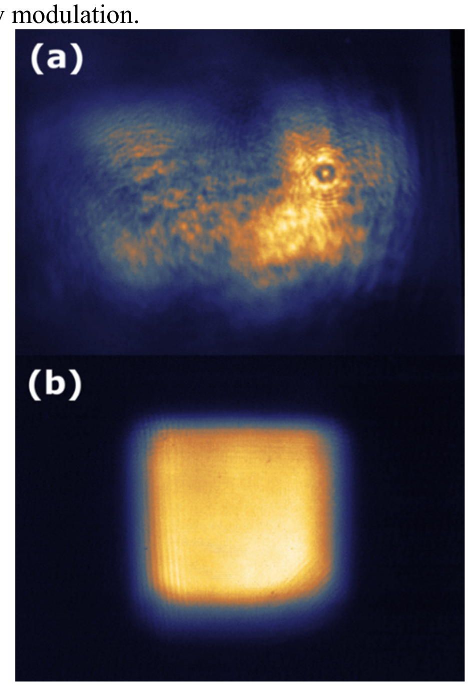

Figure 3: UV laser image measured at the virtual cathode. (a) is taken without MLA, and (b) is taken with MLA.

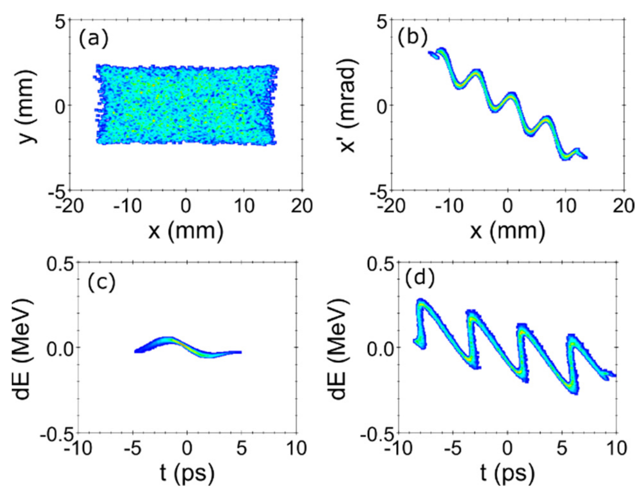

Figure 4: Start-to-end simulated beam images. (a) beam image at the entrance to the transverse wiggler. (b) horizontal phase space after the transverse wiggler. (c) longitudinal phase space before the EEX beamline. (d) longitudinal phase space after the EEX beamline.

During the simulations the magnetic field strength from the transverse wiggler was varied to control the bunch train parameters (Fig. 5). When the strength is matched to the critical compression condition, the longitudinal phase space starts to have vertical lines which makes density spikes as the orange curve in Fig. 2. Figure 5a shows the

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW089

longitudinal phase space at the critical compression condition and the corresponding current profile (red curve). As the magnetic field strength increases, the vertical lines on the longitudinal phase space start to rotate counter clockwise to create the folded structure on the phase space. This folding splits each spike into dual peaks. The separation between peaks increase as the magnetic field strength increases. Figure 5 b and c shows the result for a stronger field strength. Here the ratio of the field strength between a, b and c cases is 1:1.6:2.3.

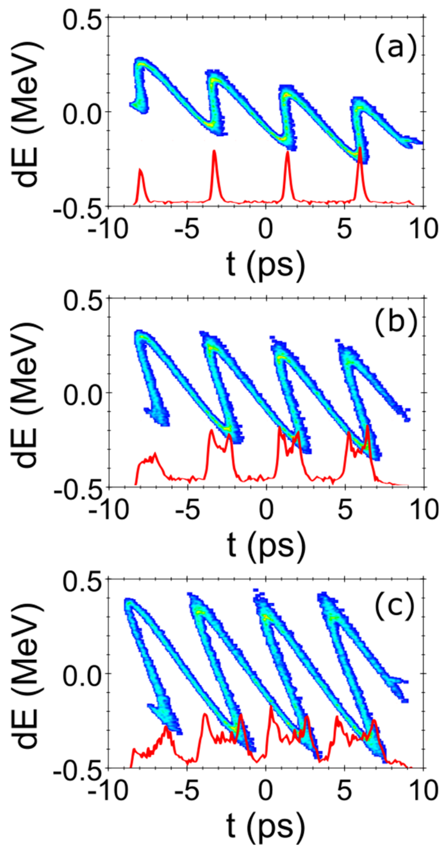

Figure 5: Start-to-end simulation result with different modulation amplitude. Magnetic field strength applied to the beam is changed to control the amplitude. The strength ratio for (a), (b) and (c) is 1:1.6:2.3.

CONCLUSION

We introduced a new method for generating a tunable bunch train. This method uses a transverse wiggler and an EEX beamline as an alternative to an energy modulator and a chicane. Since the EEX beamline converts transverse properties into longitudinal properties, the train properties, micro-bunch length and separation, can be easily controlled via the wiggler magnet and a quadrupole. Our initial design of the transverse wiggler uses permanent magnets in a Halbach array with maximum dimension of 5 cm wide x 1 cm long x 1 cm gap. This array can easily be installed on a linear motion actuator so the gap can be controlled to change the field strength applied to the beam. More details will be covered in a journal publication (in preparation).

ACKNOWLEDGEMENTS

This work is supported by Argonne's LDRD program, under Project No. PRJ1006621. Also, the work is supported by the Department of Energy, Offices of HEP and BES, under Contract No. DE-AC02-06CH11357.

REFERENCES

[1] G. Stupakov, "Using the beam-echo effect of generation of short wavelength radiation", *Phys. Rev. Lett.*, vol. 102, pp. 074801, 2009.

[2] S. Antipov et al., "Subpicosecond bunch train production for a tunable mJ level THz source", *Phys. Rev. Lett.*, vol. 111, pp. 134802, 2013.

[3] P. Emma, Z. Huang, K.-J. Kim, and P. Piot, "Transverse-to-longitudinal emittance exchange to improve performance of high gain free electron lasers", *Phys. Rev. ST Accel. Beams*, vol. 9, pp. 100702, 2006.

[4] G. Ha et al., "Precision control of the electron longitudinal bunch shape using an emittance exchange beam line", Phys. Rev. Lett. 118, 104801 (2017).

[5] A. A. Zholents and M. S. Zolotorev, "A new type of bunch compressor and seeding of a short wave length coherent radiation", ANL/APS/LS-327 (2011).

[6] G. Ha, M. E. Conde, D. S. Doran, W. Gai, and J. G. Power, "Preliminary Simulations on Chirpless Bunch Compression using Double-EEX Beamline", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 3862-3864. doi:10.18429/JACoW-IPAC2017-THPAB062

[7] J. Seok, G. Ha, J. G. Power, M. Conde and M. Chung, "Preparation for an Emittance Exchange Based Bunch compression Experiment at Argonne Wakefield Accelerator Facility," *2018 IEEE Advanced Accelerator Concepts Workshop (AAC)*, Breckenridge, CO, USA, 2018, pp. 1-5. doi:10.1109/AAC.2018.8659409

[8] http://www.pulsar.nl/gpt

[9] M. E. Conde *et al.*, "Research Program and Recent Results at the Argonne Wakefield Accelerator Facility (AWA)", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2885-2887. doi:10.18429/JACoW-IPAC2017-WEPAB132

[10] A. Halavanau *et al.*, "Spatial control of photoemitted electron beams using a microlens-array transverse shaping technique", *Phys. Rev. Accel. Beams,* vol. 20, pp. 103404, Apr. 2017.