A PASSIVE LINEARIZER FOR BUNCH COMPRESSION

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Abstract

In high gain free electron laser (FEL) facility design and operation, a high bunch current is required to get lasing with a reasonable gain length. Because of the current limitation of the electron source due to the space charge effect, a compression system is used to compress the electron beam to the exact current needed. Before the bunch compression, the nonlinear energy spread due to the finite bunch length should be compensated; otherwise the longitudinal profile of bunch will be badly distorted. Usually an X band accelerating structure is used to compensate the nonlinear energy spread while decelerating the beam. But for UV FEL facility, the X band system is too expensive comparing to other system. In this paper, we present a corrugated structure as a passive linearizer, and the preliminary study of the beam dynamics is also shown.

INTRODUCTION

In a high gain free electron laser facility, the electron beam will be accelerated and compressed before lasing. Because of the finite length of the electron beam and the sinusoidal accelerating voltage of the RF field, a nonlinear energy chirp has been induced. With this energy chirp, a ramped or a spiky [1] [2] current profile will be generated after the compressor, which will cause the partial lasing to the whole bunch and prevent getting higher peak current. To correct the nonlinear energy chirp, a higher harmonic RF linearizer was proposed and successfully used [2] [3] [4].

The corrugated structure is a metallic, cylindrical tube with periodic, shallow corrugations (see Figure 1). This structure was used for a model of roughness wake, a source of the THz radiation [5] and a dechirper for the high gain FELs [6]. By choosing the parameters of the structure, one can change both the wake length and the amplitude of the wake. With these two wake function parameters, one can easily match the duration (bunch length) and the amplitude of the nonlinear energy chirp.

In this paper, we will report the principle to setup a passive linearizer and the application to the Dalian UV FEL facility.

THE CORRUGATED STRUCTURE AS AN ENERGY CHIRP LINEARIZER

The structure of the corrugated cylindrical pipe is shown in Figure 1. The pipe radius is a, the corrugation periodis p, the corrugation gap is g, and the corrugation depth isδ, while p,δ « a, and $\delta \gtrsim$ p. The earlier work on corrugated structure [7] [8] [9] has shown that when a short, ultra-relativistic charged beam passes through the structure, a strong fundamental mode with a frequency above the cut-off frequency of the cylindrical pipe will be excited. The longitudinal point charge wakefield of this mode is approximatelywritten as,

$$W(s) = 2 \cdot \chi \cdot H(s) \cdot cos\,(k \cdot s). \quad (1)$$

The χ is the loss fact by

$$\chi = \frac{Z_0 \cdot c}{2 \cdot \pi \cdot a}, \quad (2)$$

the H(s) is a unit step function by,

$$H(s) = \begin{cases} 1, s \geq 0 \\ 0, s < 0 \end{cases}, \quad (3)$$

and the k is the wave number of the fundamental mode by

$$k = \sqrt{\frac{2 \cdot p}{a \cdot \delta \cdot g}}. \quad (4)$$

The wake potential is given by the convolution

$$W_\lambda(s) = \int W(s') \cdot \lambda(s - s')ds', \quad (5)$$

the λ (s) is the line charge density of the charged beam. And the energy loss along the beam can be easily calculated as

$$E_{loss}(s) = W(s) \cdot \lambda(s). \quad (6)$$

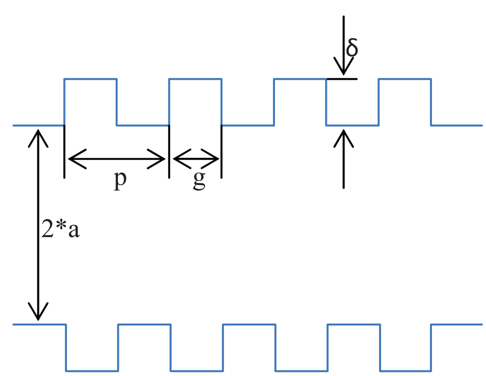

Figure 1: The drawing of the corrugated structure

Considering a beam with infinitesimal rising time and falling time, and with a length of l without any current fluctuation, we choose the wave length of the point charge wake potential twice as the bunch length. We simplify the calculation by only considering the field within the beam. The result is written as

$$E_{loss}(s) = -2 \cdot \chi \cdot \lambda \cdot \frac{l}{\pi} \cdot sin\,(\frac{\pi}{l} \cdot s). \quad (7)$$

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And some results are shown in Figure 2.

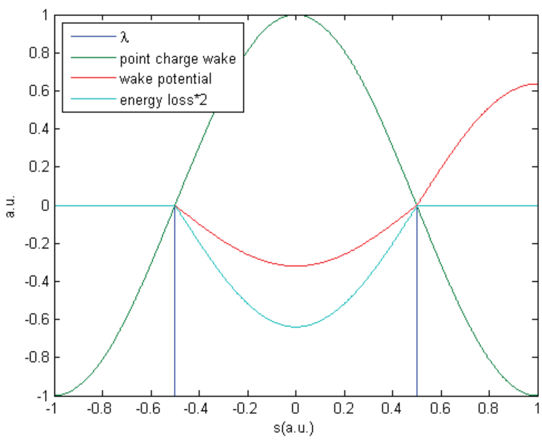

Figure 2: The energy loss along the beam. The energy loss (cyan) is multiplied by a factor of 2; otherwise it overlaps with the wake potential. The amplitude of the line charge density of the beam and the loss factor of the point charge wake function are normalized

In this case, the corrugated structure induced energy loss along the bunch is with a sinusoidal waveform and with a wavelength of two times as the bunch length, which could be used as a linearizer for the temporary phase space manipulation. This structure will work as the harmonic cavity but with short wavelength and lower correcting voltage.

To optimize the parameters of the corrugated structure for linearizing the energy chirp, one should find out the proper wavelength κ and the loss factor χ. With a given quadratic energy chirp and the beam current, we can get the loss factor through equation 7 and by equation 2 one can determine the radius of the corrugated structure. Then by properly choosing the parameters p, δ and g using the equation 4, we should get the right wavelength of the point charge wake potential which is twice as the bunch length. During this calculation, we must keep the condition of p, δ « a, and δ≳ p.

APPLICATION TO DALIAN COHERENCE LIGHT SOURCE

Dalian Coherence Light source (DCL) is a free electron laser (FEL) facility withhigh gain harmonic generation (HGHG) scheme [10]. By using the OPA technique in the seed laser system, the FEL output wavelength can be continuously tuned from 50 to 150 nm. The DCL consists of a linear accelerator, a radiator, and the beamlines (see Figure. 3). The radiatorconsists of undulators system and seeding laser system. The beamlines consist of the transport lines and experimental stations.

The linac consists of a photo-cathode RF gun, 7 SLAC-type accelerating tubes (2.856 GHz), and a magnetic bunch compressor. The linaccan deliver a high brightness electron beam to the radiator (see Table 1).

Table 1: Main parameters of the DCL linac

Parameters	Values	Units
Energy	~300	MeV
Energy spread(global)	<0.2	%
Peak Current	~300	A
Charge	~500	pC
Normalized emittance (slice)	~4	mm·mrad

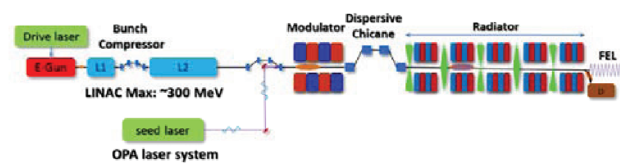

Figure 3: Schematic layout of the DCL.

In the original design, there is no X-band linearizer due to the budget limit. Because of the quadratic term of the energy chirp before the bunch compressor, we could not get the higher current, and suffer from the large peak with a long tail (see Figure 5). This turns out to be that the lasing will only take place at a small part of the whole bunch, which will limit the laser pulse energy and cause the bandwidth degradation in the long pulse mode for the energy resolved experiments.

Table 2: Main parameters of corrugated structure

Parameters	Values	Units
a	3.3	mm
p	1.25	mm
δ	0.5	mm
g	0.9	mm
L (total length)	0.45	m

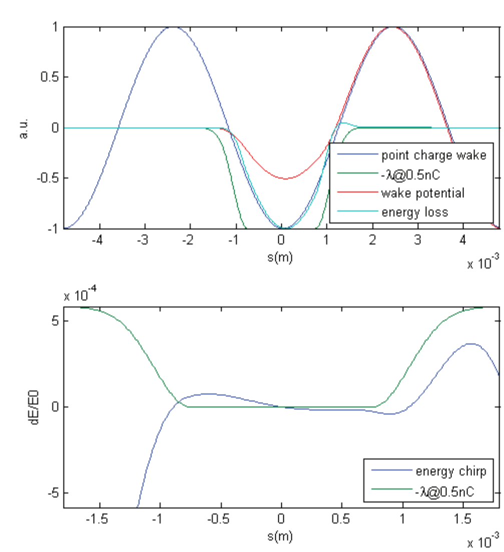

Figure 4: Linearizing of the energy chirp. The energy loss along the bunch (up) and the final result (bottom).

To use the corrugated structure as a linearizer for the DCL, we must choose the proper corrugated parameters by the method mentioned above. Through some calculations and tests due to the imperfect beam profile, the parameters are shown in Table 2, and the estimated result of energy chirp linearizing is shown in Figure 4. It shows the quadratic chirp has been compensated in the middle, but remains in the head and tail.

To ensure this structure will work in a real linac, the code LiTrack [11] is used for simulation study on the longitudinal tracking (see Figure 5). The results shows that by optimizing the parameters of the corrugated structure, we can make current profile of the compressed beam even more flat that the X-band case. But there still has a sharp edge due to the finite rising time of the bunch. The sensitivity of the jitter is also studied by the code for the three cases. With a set of given hardware jitters, the jitter of the beam parameters is not significantly from one to another (see Table 3).

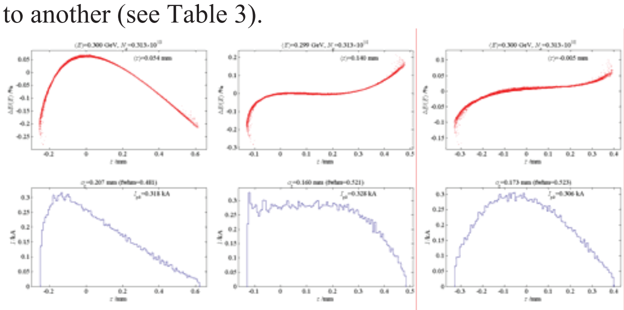

Figure 5: The longitudinal phase space at the exit of the linac. Without linearizing (left), with corrugated structure (middle), with X-band (right)

Table 3: Jitter budget comparison

Parameters	without linearizing	corrugated structure	X-band
R56,opt.(mm)	-50	-75	-75
Beam energy (0.1%)	1.0	0.87	0.96
Peak current (%)	5.3	3.4	6.2
Arriving time (fs)	132	173	186

The code Elegant [12] is used for the 3D beam dynamics study taking account of the strong transverse wake of the structure [9] with the structure wake field, coherence synchrotron radiation (CSR) and longitudinal space charge (LSC) effect(see Figure 6). The result shows there is a minimum emittance around the 50um displacement of the corrugated structure. This means that the transverse wake of the structure gives a kick along the bunch in advance which is opposite to the kick due to the CSR, and compensates the emittance mismatching by the CSR, at some point.

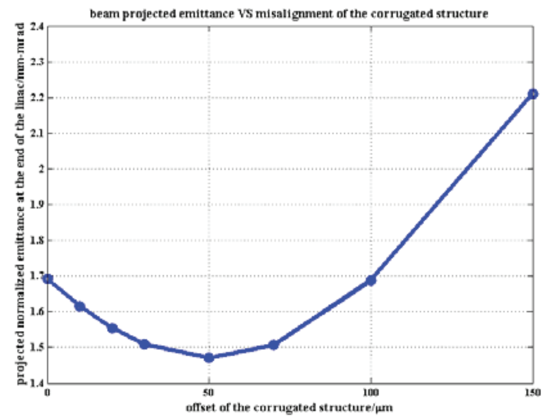

Figure 6: The emittance growth due to the displacement of the corrugated structure.

CONCLUSION

The corrugated structure could be used as a linearizer for the linac. In practise, the structure could be divided into several sections to be more flexible to fit to the beam parameters changing.

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REFERENCES

[1] G. De Ninno, et. al., FEL COMMISSIONING OF THE FIRST STAGE OF FERMI@ELETTRA, WEPC55, Proceedings of FEL2009.
[2] H. Edwards, et. al., 3.9 GHz CAVITY MODULE FOR LINEAR BUNCH COMPRESSION AT FLASH, MO304, Proceedings of Linear Accelerator Conference LINAC2010.
[3] Linac Coherent Light Source (LCLS) Conceptual Design Report, 2002
[4] SCSS X-FEL Conceptual Design Report, 2005
[5] K. Bane and G. Stupakov, Nucl. Inst. Meth.A 677 (2012) 67~73.
[6] K. Bane and G. Stupakov, Corrugated Pipe as a Beam Dechirper, SLAC-PUB-14925, 2012
[7] S. Kheifets, Longitudinal Impedance of Simple Cylindrically Symmetric Structures, SLAC-PUB-4133, 1986
[8] K.L.F. Bane, G. Stupakov,Impedance of a Beam Tube with Small Corrugations, XX International Linac Conference
[9] Karl L.F. Bane, The Resonator Impedance Model of SurfaceRoughness Applied to the LCLS Parameters, SLAC-AP-117, 1999
[10] Conceptual design report of Dalian Coherence Light source, 2011
[11] K.L.F. Bane, P. Emma, Litrack: A Fast Longitudinal Phase Space Tracking Code with Graphical User Interface, SLAC-PUB-11035
[12] M. Borland, elegent: A Flexible SDDS-Compliant Code for Accelerator Simulation, Advanced Photon Source LS-287, September 2000.

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