ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUP003

DESIGN OF A MAGNETIC BUNCH COMPRESSOR FOR THE THz SASE FEL PROOF-OF-PRINCIPLE EXPERIMENT AT PITZ*

H. Shaker†, P. Boonpornprasert, G. Georgiev, G. Koss, M. Krasilnikov, X. Li, A. Lueangaramwong, F. Mueller, A. Oppelt, S. Philipp, F. Stephan, G. Vashchenko, T. Weilbach
DESY, Zeuthen, Germany

Abstract

For pump-probe experiments at the European XFEL, a THz source is required to produce intense THz pulses at the same repetition rate as the X-ray pulses from XFEL. Therefore, an accelerator-based THz source with identical electron source as European XFEL was suggested [1] and proof-of-principle experiments utilizing an LCLS I undulator will be performed at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The main idea is to use a 4nC beam for maximizing the SASE radiation but also to allow different radiation regimes, a magnetic bunch compressor can be used. This helps e.g. to reduce the saturation length inside the undulator and also to study super-radiant THz radiation. In this paper a design of a chicane type magnetic bunch compressor re-using HERA corrector magnets is presented.

INTRODUCTION

To demonstrate an accelerator-based tunable THz source for pump-and-probe experiments at the European XFEL, a proof of principle study is started at the Photo-Injector Test Facility at DESY in Zeuthen site (PITZ) [1-8]. This experiment will be done by using the electron beam produced at PITZ and by using LCLS-I undulators inside the existing accelerator tunnel extension. Since PITZ and European XFEL electron sources are identical, the X-ray and THz radiation can be produced with identical bunch train structure. This means for every X-ray pulse a corresponding THz pulse can be provided for the pump-and-probe experiments.

With nominal 4 nC bunch charge, 200 A peak current and 16-25 MeV, this experiment wants to demonstrate a near one milli-joule pulse energy radiation in the frequency range of 3-15 THz based on the SASE mechanism. To have flexibility to work with lower charges and shorter initial bunches a magnetic bunch compressor is required. By beam compressing, we will have shorter bunch length with higher peak current. This effect reduces the saturation length inside the undulator and also opens the door for coherent or super-radiant radiation studies [9]. In this paper, a design for a chicane-type magnetic bunch compressor will be presented. This bunch compressor will be installed in the main PITZ tunnel and since PITZ is a multi-purpose machine minimum beamline modification is desirable. To take advantages of available components, we will re-use corrector magnets from earlier HERA machine at DESY to assemble the bunch compressor. Figure 1 shows the end-section of the PITZ beamline in the main tunnel. In this figure, you can see the vertical chicane and the rotated beam dump which will be added to the current beamline. We considered both the desired bunch compressing magnitude and available spaces in the beamline to find an optimum design.

R_{56} is a main parameter of the bunch compressor and can be expressed in the first order by $R_{56}=\Delta z/\delta$, where Δz is the difference between output and input bunch lengths and δ is the relative energy spread. Inside a chicane type bunch compressor without any quadrupoles the higher energy particles travels less distance then it has negative R_{56}. This means we need a positive energy chirp for bunch compressing. The positive energy chirp can be produced by changing the booster phase. The acceptable maximum relative energy spread can be calculated based on 1-D FEL theory. Based on this theory the relative energy spread should be less than the Pirece parameter (ρ) [10]:

$$(1)\quad \begin{cases} \rho = \left[\frac{I}{\gamma^3 I_A}\frac{\lambda_u{}^2}{2\pi\sigma_x\sigma_y}\frac{(K\times[JJ])^2}{32\pi}\right]^{1/3} \\ [JJ] = J_0(\xi) - J_1(\xi)\,, \xi = \frac{K^2}{2(2+K^2)} \\ I_A \approx 17kA \end{cases}$$

For the LCLS-I undulator, the undulator K parameter is 3.49 and its periodic length (λ_u) is 3 cm. For the rms beam size (σ_x and σ_y) of about 1 mm and peak current (I) of 200 A, the Pierece parameter is equal to 0.015 and 0.01 for the beam energy of 16 MeV and 25 MeV, respectively. To cover the full energy range, the maximum 1% energy chirp is selected for our design. Using equation (1), R_{56} would be about -0.18m for maximum 6ps compression from the bunch center for each side. This means for a relative short bunch we can compress a bunch to sub-picosecond level. R_{56} is only dependent to the first drift length (L_1), dipole length (L_d) and the deflecting angle (θ) and it can be calculated roughly using this equation [11]:

$$(2)\quad R_{56} \approx -\theta^2(2\times L_1 + 4/3\times L_d)$$

To install the bunch compressor, there are two free spaces available at the end of PITZ beamline, one between 1st and 3rd dipole in Second High Energy Dispersive Arm (HEDA2) and another one between the 3rd HEDA2's dipole and the tunnel wall. But both spaces are not enough alone to fit the bunch compressor. Therefore we decided to use a vertical setup which helps us to use both spaces without any need to remove the HEDA2 dipoles. Based on this setup, the minimum acceptable angle for the chicane is 16.77° to not hit the 3rd dipole of HEDA2.

* Work supported by the European XFEL
† hamed.shaker@desy.de

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUP003

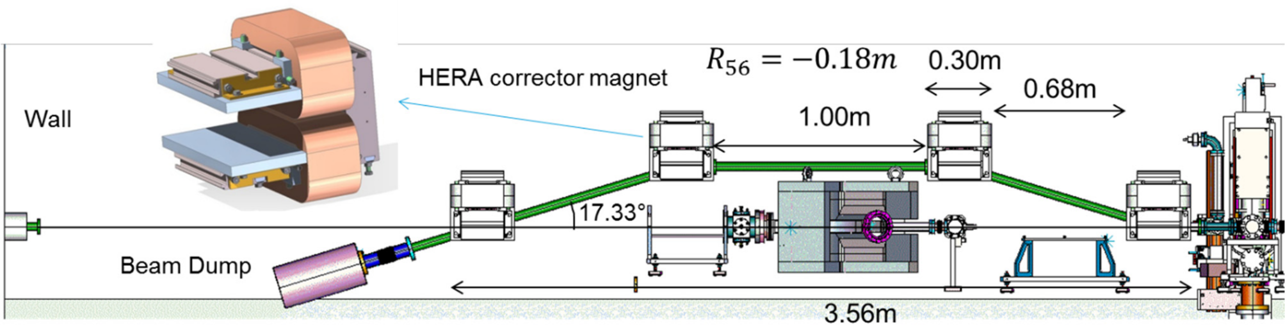

Figure 1: End-section of PITZ beamline in the main tunnel including the vertical chicane and the rotated beam dump.

CHICANE CONFIGURATION

As mentioned previously, the available HERA corrector magnets will be used to build this bunch compressor. They are rectangular dipoles with a pole length of 30cm, a gap of 5cm and maximum magnetic field of 0.155T. Figure 2 and Table 1 show the layout and parameters of the HERA corrector magnet, respectively. As you can see in Figure 1 and by considering the dipole pole lengths, the maximum available projected drift between two first dipoles is 0.68m. To find the chicane angle for our desired R_{56}=-0.18m, which was calculated in the last section, we used the MADX code [12]. We found θ=17.33° which is larger than our threshold (16.77°).

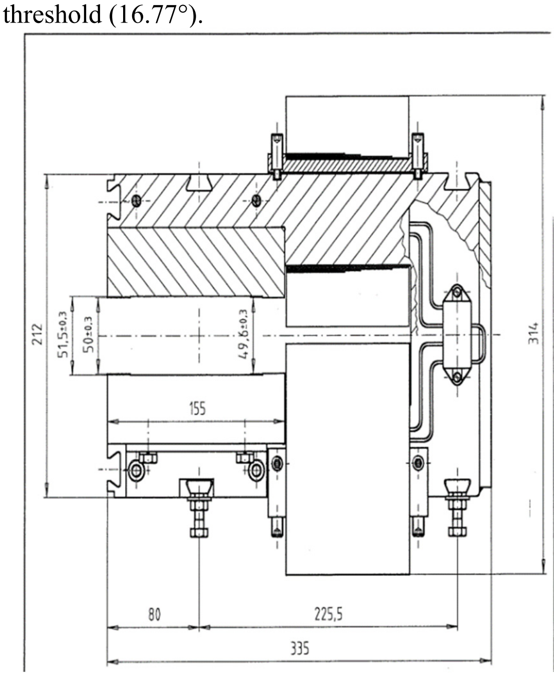

Figure 2: Layout of a HEDA corrector magnet (CH Type).

Table 1: HEDA Corrector Magnet Specifications

Parameter	Specification
Pole Shape	Rectangular
Pole length	300 mm
Pole Gap	50±0.3 mm
Maximum field at 2.4A	0.155 T

BUNCH COMPRESSION

For low charges, we used the CSRtrack code [13] to study the bunch compression of our designed chicane.

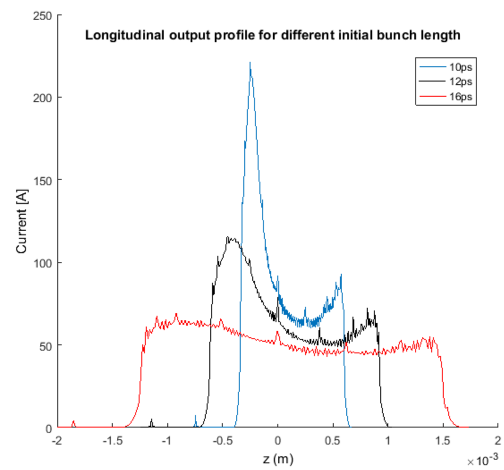

Figure 3: Simulated bunch compression for different initial bunch length using the CSRtrack code. The tail is on the left side.

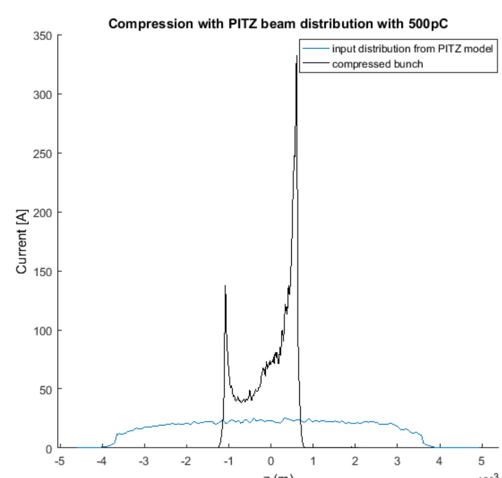

Figure 4: Simulated bunch compression of the PITZ beam distribution with 500 pC bunch charge and 17 MeV mean energy using CSRtrack code. The tail is on the left side.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUP003

Firstly, as input for the chicane, different simple particle distributions with a flat-top longitudinal profile, 30A peak current, 20.5MeV energy and various bunch lengths were constructed. Figure 3 shows the chicane's output distributions. For relative long bunches the compression is more uniform but when we use shorter bunches, we see a peak at the tail of the bunch. For the 10ps case this peak is shorter than 0.8ps. As a second step, a PITZ beam distribution produced by ASTRA [14] was used as the input. The initial bunch length was about 24ps and the total charge was 500pC. The peak current was about 22A and the energy was 17MeV. Figure 4 shows the input and output profiles. The bunch was compressed with two peaks in both ends and each peak has about 0.3ps FWHM which makes it ideal for super-radiant radiation study. In general word, a peak at the tail has an interesting effect. It can stimulate the seeding for the rest of the bunch. We haven't considered the effect of dipole fringe files but since our compression factor is usually below 10, dipole's fringe field effects can be ignored.

OTHER CONSIDERATIONS

One screen station will be installed in the second drift of the bunch compressor for beam diagnostic, energy collimation and transverse modulation for seeding [15]. We also want to install a THz CTR radiation detector station after the chicane to measure the bunch length. Another station is also considered to be installed after the third dipole to measure synchrotron radiation which can be used to measure the bunch length. The maximum transverse beam size is 6 mm (~ 2mm rms) which means both 36 mm and 63 mm standard size vacuum beam-pipe can be used for the beam transportation inside the chicane.

CONCLUSION

A bunch compressor is a very useful tool to generate and study different kind of THz radiation. Further study with higher bunch charges in the nC range is needed in order to see if it is possible to compress such high bunch charges without big beam distortion.

REFERENCES

[1] E.A. Schneidmiller, M.V. Yurkov, M. Krasilnikov, F. Stephan, "Tunable IR/THz Source for Pump Probe Experiments at the European XFEL," in *Proc. FEL'12*, Nara, Japan, Aug. 2012, paper WEPD55.

[2] P. Boonpornprasert *et al*., "Extension of the PITZ Facility for a Proof-of-Principle Experiment on THz SASE FEL", presented at the 39th Int. Free Electron Laser Conf. (FEL'19), Hamburg, Germany, Aug. 2019, paper TUP001.

[3] X. Li *et al.*, "Progress in Preparing a Proof-of-Principle Experiment for THz SASE FEL at PITZ", presented at the FEL'19, Hamburg, Germany, Aug. 2019, paper TUP002.

[4] X. Li et al., "Design Studies of a Proof-of-Principle Experiment on THz SASE FEL at PITZ", in Proc. IPAC'19, Melbourne, Australia, May 2019, pp. 1713-1716. doi:10.18429/JACoW-IPAC2019-TUPRB018

[5] P. Boonpornprasert *et al.*, "Experimental Optimization and Characterization of Electron Beams for Generating IR/THz SASE FEL Radiation with PITZ", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 2650-2653. doi:10.18429/JACoW-IPAC2017-WEPAB033

[6] P. Boonpornprasert *et al.*, "Calculations for a THz SASE FEL Based on the Measured Electron Beam Parameters at PITZ", FEL17, NM, US, Aug. 2017. doi:10.18429/JACoW-FEL2017-WEP004

[7] P. Boonpornprasert, M. Krasilnikov, F. Stephan, and B. Marchetti, "Numerical Simulations of a Sub-THz Coherent Transition Radiation Source at PITZ", in *Proc. FEL'15*, Daejeon, Korea, Aug. 2015, paper MOP033, pp. 97-100.

[8] P. Boonpornprasert *et al.*, "Start-to-End Simulations for IR/THz Undulator Radiation at PITZ", *in Proc. FEL'14*, Basel, Switzerland, Aug. 2014, paper MOP055, pp. 153-158.

[9] N. Stojanovic *et al.*, "Accelerator- and laser-based sources of high-field terahertz pulses", *Journal of Physics B: Atomic, Molecular and Optical Physics*, Volume 46, Number 19, September 2013.

[10] M. Venturini, "Basics on FEL physics; undulators; high-level machine-design parameters", USPAS, Rutgers University, June 2015.

[11] D. Nguyen *et al.*, "RF Linac for High-Gain FEL Bunch Compression", USPAS, Los Alamos National Laboratory, June 2014.

[12] MAD-Methodical Accelerator Design, http://madx.web.cern.ch/madx/.

[13] M. Dohlus, CSRtrack code, http://www.desy.de/xfel-beam/csrtrack/.

[14] K. Floettmann. ASTRA code, https://www.desy.de/~mpyflo/.

[15] X. Zhu *et al.*, "Theoretical and numerical analyses of a slit-masked chicane for modulated bunch generation", *Journal of Instrumentation*, vol. 10, Oct. 2015.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI