

Feasibility of Double Diffraction Radiation Target Interferometry for Compact Linear Accelerator Micro-train Bunch Spacing Diagnostics

D A Shkitov^{1*}, A P Potylitsyn¹, A S Aryshev², J Urakawa²

¹ Tomsk Polytechnic University, 30, Lenin St., Tomsk, 634050, Russia

² High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

E-mail: shkitovda@tpu.ru

Abstract. In this paper the simulation of the interaction between micro-train electron beams with different parameters of energy, bunch length, bunch spacing which chosen for KEK LUCX accelerator facility and a double diffraction radiation target is considered. Calculation model and several accepted assumptions on the first step of our investigations are also described. Conducted researches allow us to conclude that applying the double diffraction radiation target interferometry as a tool for non-invasive micro-train bunch spacing diagnostics for compact linear accelerator is possible.

1. Introduction

Short-pulse THz systems are used in time-domain spectroscopy to understand biological processes and to create two- and three-dimensional images [1, 2]. Much of the recent interest in terahertz (0.1 – 10 THz) radiation comes from its ability to penetrate deep into many organic materials without the damage associated with ionizing radiation such as X-rays.

Nowadays there are a few ways to generate intense beams of THz radiation: optically pumped terahertz lasers, photomixing of near-IR lasers, backward-wave oscillators, direct multiplied sources and nonlinear optical processes occurring when an intense laser beam interacts with a material [3]. Another promising technique is to generate short, high-brightness THz-frequency coherent radiation pulses using a micro-train electron beam (THz sequence of a several fs-length electron bunches) of a compact accelerator. That micro-train beam is expected on LUCX (Laser Undulator Compact X-ray) accelerator facility at KEK. In this case, development of a robust and non-invasive micro-train bunch spacing diagnostics obtains vast importance.

Recent progress in double diffraction radiation (DR) target interferometer (full abbreviation – DDRTI) development [4] gives an excellent basis for such diagnostics implementation. When bunched electron beam passes through the slit of a double DR target (two conducting screen) it emits coherent radiation with intensity being dependent on double target parts relative position (interferogram). This interferogram can be measured when one part of the target moves with respect to another along the beam trajectory.



2. Experimental setup

The LUCX accelerator facility [5] expects to generate a few tens of MeV electron bunches with 100 – 300 fs duration and variable micro-bunch spacing [6]. There are two possible locations along the beam line which can be used for the DDRTI realization: “THz section” right after the 3.6-cell RF gun and the section downstream of 12-cell accelerating structure, so-called “Compton section”. The principal difference of these two locations is the electron beam energy. It was proposed to use recently tested quasi-optical THz detector (QOD) [7] for interferometer commissioning. The main electron beam parameters for both possible DDRTI locations as well as QOD parameters are summarized in table 1.

Table 1. LUCX electron beam and QOD parameters.

	“THz section”	“Compton section”
Electron energy	8.25 MeV	30 MeV
Micro-bunch length	100 fs	300 fs
Transverse size (x, y)	200 μ m	
Micro-bunch spacing	0 – 10 ps	
Normalized emittance (x, y)	5π mm \times mrاد	
Micro-bunch charge	100 pC	
Number of micro-bunches	2 – 16	
Electron energy spread	~1%	
QOD Spectral range	0.1 – >1.0 THz	
QOD Aperture	10 mm	
Minimum distance from output window to QOD	60 cm	
Maximum distance	a few meters	

3. Model assumptions

As a first step to investigate feasibility of micro-train bunch spacing diagnostics by double DR target interferometry the simulation was performed with several reasonable assumptions. First, the pseudophoton diffraction approach [8, 9] was used but without the far-field approximation. The main idea of this approach is that the relativistic particle electromagnetic (EM) field can be described as a field of so-called pseudophoton which behaves like a real photon. That’s why the expression of the single particle EM field, accounting the phase factor and knowledge of the bunch form-factor are only needed to perform a simulation. Also in the model the finite size of two rectangular flat plates (parts) in double DR target was considered. Other assumptions were as follows:

- THz detector spectral sensitivity and the influence of the output vacuum window (glass transmission) onto THz spectrum were not taken into account.
- Calculation was done for point-like detector without accounting for the detector aperture.
- Electromagnetic field of charged particles had only transverse component.
- The only longitudinal bunch size with gaussian distribution was considered.

In order to find out how the bunch length and bunch spatial distribution in micro-train influence to the interferogram shape the simulation was carried out for electron beam parameters of two energies and bunch lengths corresponding to the “THz section” and “Compton section” of the LUCX accelerator according to table 1. The simulation parameters for electron beam, target and detector location are presented in table 2.

It is important to notice that for these two different cases of electron beam energy but for the same detector location the radiation is registered in two zones: far-field and near-field.

Table 2. Total simulation parameters.

	“THz section”	“Compton section”
Electron energy	8.25 MeV ($\gamma \approx 16$)	30 MeV ($\gamma \approx 59$)
Micro-bunch length	100 fs (30 μm)	300 fs (90 μm)
Basic micro-bunch spacing	1 ps (300 μm)	
Radiation wavelength range	0.03 – 3.0 mm	
Target slit width	2 mm	
Target-to-detector distance	700 mm far-field zone	700 mm near-field zone
Target dimensions (z, x)	46×20 mm ²	
Target tilt angle to the trajectory	$\pi/4$	
Point of detector	(0,0)	
Interferograms step	20 μm	

4. Simulation results

Interferograms for different number of bunches per train are presented at the following figures (figure 1 to figure 5). On each figure the number of bunches per train were varied from 1 to 5 and corresponded interferograms were plotted. The lower curves are calculated for 1 bunch and upper curves are simulated for 2, 3, 4 and 5 bunches in the micro-train respectively. The plot sets for different micro-bunch spacing l_{ij} , i.e. the distance between “ i ”-th and “ j ”-th bunch as well as for the different RMS electron bunch lengths σ are shown at the figure 6 and figure 7.

It is clear that the figure 1, 2 and 4, 5 shows some limit value of the bunch spacing, i.e. if the spacing becomes smaller than some limit value it is impossible to derive micro-train spatial distribution from the interferogram’s shape. However this value depends on the combination of electron beam energy and the bunch length as can be seen from the figure 2, 3 and 5 which are obtained for the same micro-bunch spacing l_{ij} .

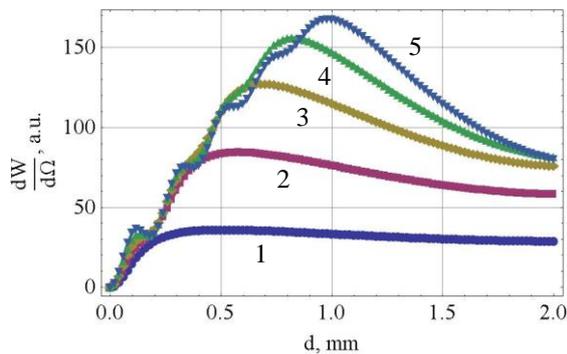


Figure 1. Simulated interferograms for different number of bunches per train: 1 to 5. $l_{ij} = 200 \mu\text{m}$, 8.25 MeV and $\sigma = 30 \mu\text{m}$.

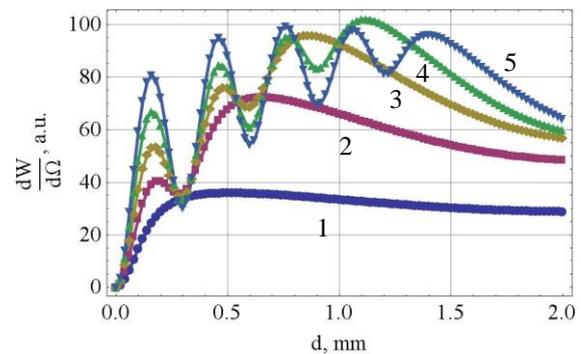


Figure 2. Simulated interferograms for different number of bunches per train: 1 to 5. $l_{ij} = 300 \mu\text{m}$, 8.25 MeV and $\sigma = 30 \mu\text{m}$.

It is important to notice that from the interferogram shape one can obtain the exact micro-train structure because the number of peaks in the interferograms corresponds to the number of the micro-

bunches what is distinctly seen on the figure 2 and 5. Furthermore, it was observed that the position of the first minimum of the interferogram is almost equal to the distance between bunches.

Interferograms became even more clear and demonstrative for higher values of the bunch spacing.

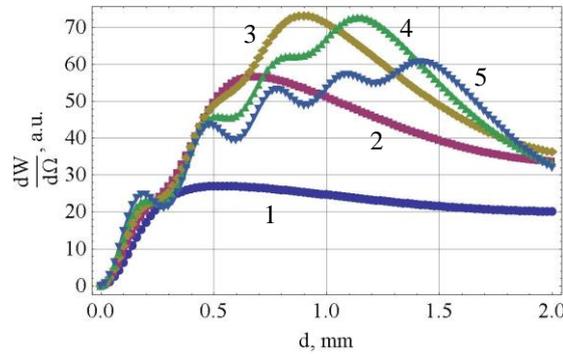


Figure 3. Simulated interferograms for different number of bunches per train: 1 to 5. $l_{ij} = 300 \mu\text{m}$, 8.25 MeV and $\sigma = 90 \mu\text{m}$.

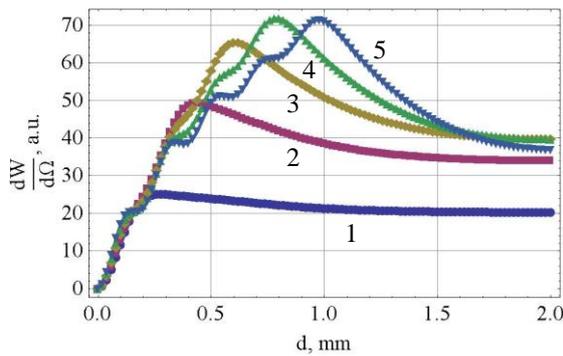


Figure 4. Simulated interferograms for different number of bunches per train: 1 to 5. $l_{ij} = 200 \mu\text{m}$, 30 MeV and $\sigma = 90 \mu\text{m}$.

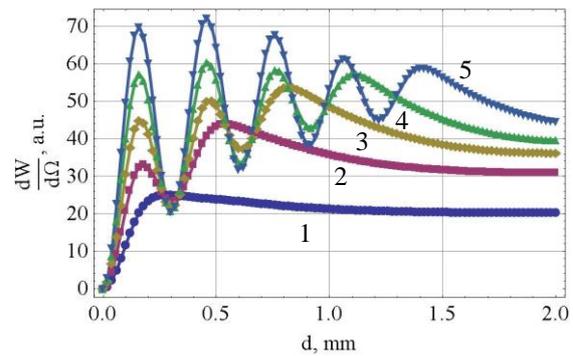


Figure 5. Simulated interferograms for different number of bunches per train: 1 to 5. $l_{ij} = 300 \mu\text{m}$, 30 MeV and $\sigma = 90 \mu\text{m}$.

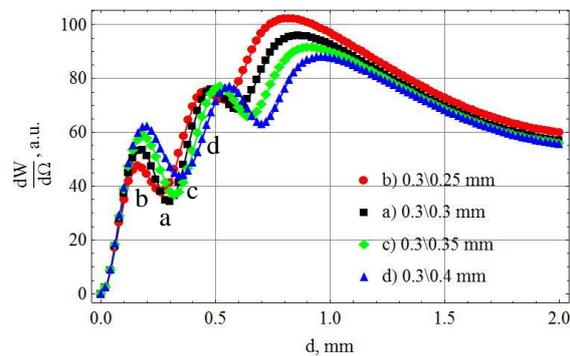


Figure 6. The interferograms simulated for different spacing between 3 bunches in the micro-train (8.25 MeV and $\sigma = 30 \mu\text{m}$).

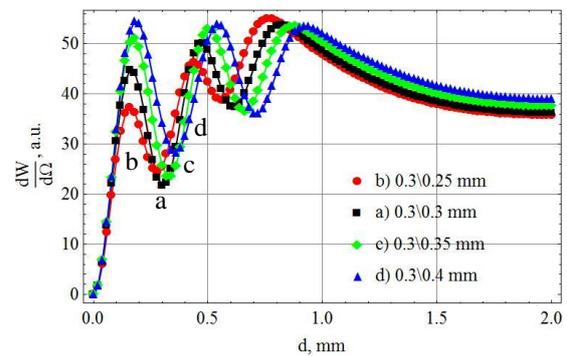


Figure 7. The interferograms simulated for different spacing between 3 bunches in the micro-train (30 MeV and $\sigma = 90 \mu\text{m}$).

Figure 6 and 7 shows the different bunch spacing within the micro-train influence onto DDRTI interferogram simulated for the different bunch lengths of 30 μm and 90 μm respectively. The values of l_{12} and l_{23} for corresponded plots are resented in table 3. As it was expected the maxima and minima

positions of interferogram were slightly shifted when l_{23} was varied. In this case the position of the first minimum is approximately equal to the average distances between 3 bunches l_{12} and l_{23} . In addition it is noted that for reverse values of spacing ($l_{12} \setminus l_{23}$ and $l_{23} \setminus l_{12}$) the interferograms shapes are the same.

Table 3. Bunch spacing parameters for figure 6 and 7.

Figure	Bunch spacing	black (a)	red (b)	green (c)	blue (d)
6	$l_{12} \setminus l_{23}$	0.3 \ 0.3 mm	0.3 \ 0.25 mm	0.3 \ 0.35 mm	0.3 \ 0.4 mm
7	$l_{12} \setminus l_{23}$	0.3 \ 0.3 mm	0.3 \ 0.25 mm	0.3 \ 0.35 mm	0.3 \ 0.4 mm

Figure 8 shows the 3 bunch micro-train interferograms calculated for the different spacing l_{12} and l_{23} but for the same average spacing. Bunch spacings for curves from bottom to top were equal to: 0.5 \ 0.5 (a), 0.45 \ 0.55 (b), 0.4 \ 0.6 (c), 0.35 \ 0.65 (d), 0.3 \ 0.7 (e) and 0.2 \ 0.8 (f) mm respectively. The interferogram shape for the cases where the spacing differences were less than 40% relatively to the average value remains the same (first two curves from the bottom). And for spacing differences more than 40% the interferogram shape totally changes in comparison with the bottom curve what leads to the inability to determine the number of bunches. Furthermore this observation sets some boundary of applicability for maximum space difference between bunches in the micro-train that can be found from the interferogram.

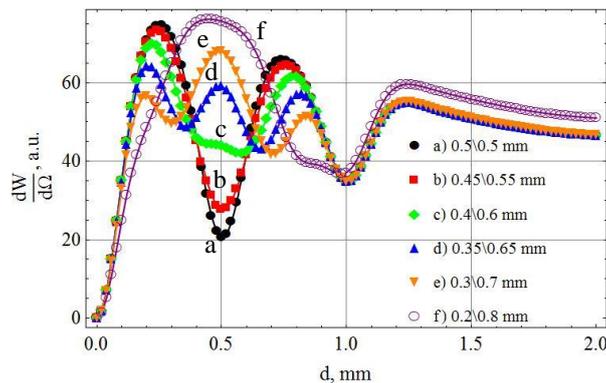


Figure 8. The interferograms simulated for different spacing between 3 bunches in the micro-train (30 MeV and $\sigma = 90 \mu\text{m}$).

Nevertheless the qualitative consideration of the above-mentioned assumptions in simulations (detector aperture and transversal size of bunches) allows to conclude that it will lead to the definite interferograms shape changing. Its shape will become smoother, the minimum around zero ($d = 0$) will be shifted towards higher values and differences between maxima and minima will become smaller. But the positions of minima will almost remain unchanged because micro-train form-factor has the determining significance and contains strongly expressed harmonics. As is well known the longitudinal electromagnetic field component of the charged particles is γ times less than transverse component and can significantly affect the results for the low electron beam energy micro-train characterization. In the relativistic case presented here the effect is negligible. However the longitudinal field component will be taken into account in the future calculation.

5. Conclusions and plans

The obtained result demonstrates a clear dependence of simulated interferograms shape on the bunch spacing in the micro-train. The possibility of the number of bunches in micro-train direct observation

through the interferogram shapes was demonstrated. The average bunch spacing within the micro-train can be determined from the first minimum of the interferogram.

An additional investigation should be performed for better understanding of the micro-train beam and double DR target interferometer interaction process. As an example, the influence of the bunch form-factor shape and the beam position relative to the slit will be considered in the simulation. Accounting for the double DR target interferometer plate's adjustment inaccuracies will be implemented for better experimental setup construction and alignment. Cross-check measurements with a deflecting cavity and THz Michelson interferometer at KEK: LUCX facility is also considered.

Applying double diffraction radiation target interferometry for the non-invasive determination of the bunch spacing can lead to construction of a robust diagnostics for modern accelerators and compact THz sources.

Acknowledgments

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