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DOUBLE DIFFRACTION RADIATION TARGET INTERFEROMETRY FOR MICRO-TRAIN BEAM DIAGNOSTICS*

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Abstract

Promising technique to generate short, high-brightness THz-frequency coherent radiation pulses is to use a micro-train electron beam. That's why the creation and development of a method to diagnose a micro-train electron beam becomes essential. Recently our group starts to investigate a feasibility of double diffraction radiation (DR) target interferometry for non-invasive micro-train beam diagnostics at KEK: LUCX facility. In this report we present double DR target preparation accuracy requirements in order to minimize measurement uncertainties and increase interferometer resolution.

INTRODUCTION

Double DR target consists of two metal plates and one of them can be moved relatively to another along the beam trajectory. The coherent radiation spectra generated by electron bunches on this target allows to determine a sub-picosecond bunch length [1]. Micro-train beam is a sequence of short electron bunches with sub-ps spacing. As it was shown in [2] double DR target can be used for such a beam diagnostics measuring DR yield versus plate's displacement. The obtained tuning curve (interferogram) allows to determine a number of bunches within the micro-train through the interferograms shapes and averaged bunch spacing from the 1st minimum of interferogram.

In order to design a reliable and precise device for this aim we have to take into account different double DR target interferometer plate's adjustment inaccuracies. These inaccuracies can be as follows: inaccuracies in the mutual adjustment of plates tilt angles with respect to the beam trajectory, outer plate edge shift along the beam trajectory and other. Combination of these parameters along with manufacturing tolerances dictates the final mechanical design of the in-vacuum interferometer system. In this report the influence of such adjustment inaccuracies to the interferogram shapes is considered. The effect of the bunch form-factor shape is also presented.

At the LUCX facility [3] initially the regime with 2 bunch with possible upgrade up to 16 bunches micro-train is planned. The most recent LUCX beam parameters were assumed for interferometer simulation based on the well-known pseudophoton approach [4].

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THEORETICAL BACKGROUND

The total radiation intensity of the DR which occurs when electron beam interacts with the target can be approximately found by the following expression as:

$$\frac{\mathrm{d}^2 \mathrm{W}_{tot}}{\mathrm{d}\omega \mathrm{d}\Omega} \sim \mathrm{N}_e^2 \cdot f^2(\lambda) \cdot \frac{\mathrm{d}^2 \mathrm{W}_e}{\mathrm{d}\omega \mathrm{d}\Omega}$$

where the first term is a number of electron per bunch, the second is a bunch form-factor and the third is single electron radiation intensity. In order to take into account the interaction between bunches within the micro-train we need to modify the form-factor term [5]. It can be defined as a sum of certain number of bunches within the micro-train with the given shifts between them and given electron distributions. Thus micro-train form-factor can be written as:

$$f(\lambda) = f_z(\sigma_z, \lambda) \sum_{k=1}^{n} \exp(i \frac{2\pi l_{1k}}{\beta\lambda})$$

where f_z is the longitudinal bunch form-factor, n is the number of bunches, σ_z is the longitudinal rms bunch length, β is the electron speed and l_{1n} is the distance between 1st and nth bunch.

On Fig. 1 the micro-train form-factors for 1, 2 and 4 8.25 MeV electron bunches with gaussian distribution and spacing l_{ij} = 0.3 mm are shown.

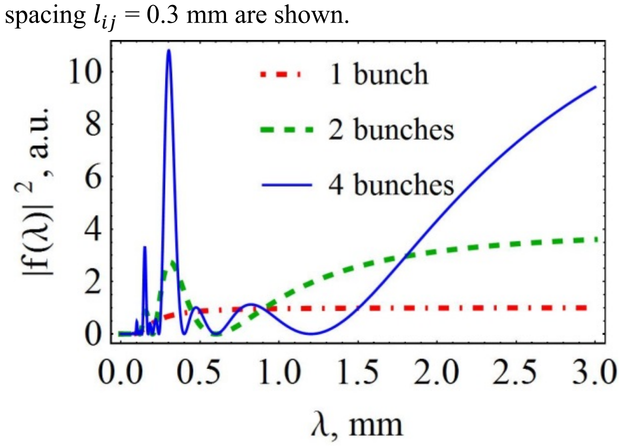

Figure 1: The form-factors for micro-trains with a few bunches with spacing l_{ij} = 0.3 mm.

As can be seen from this plot the shape of the form-factor curve for micro-train has significant difference with respect to 1-bunch form-factor. This fact has dominant influence in the double diffraction radiation target interferometry diagnostics.

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SIMULATION

Prior to target design and experimental investigations the series of calculations for various parameters of the system were performed. The principal scheme of the double DR target with our angle uncertainties notation is presented at the Fig. 2. Here a is the slit width, θ_0 is the target main tilt angle, $\delta_{1,2}$ is the rotation angle along the "X" axis which counted from main angle. The $\alpha_{1,2}$ is the rotation angle along the axis passing along the inner edge of the slit (Z = 0, X = –a/2 or a/2 respectively) when the plates are not shifted and parallel to the "Y" axis. Indices "1" and "2" corresponds to the first target plate with X < 0 and second plate with X > 0 respectively. In simulation the angles $\delta_{1,2}$ and $\alpha_{1,2}$ were set to 0 unless specified.

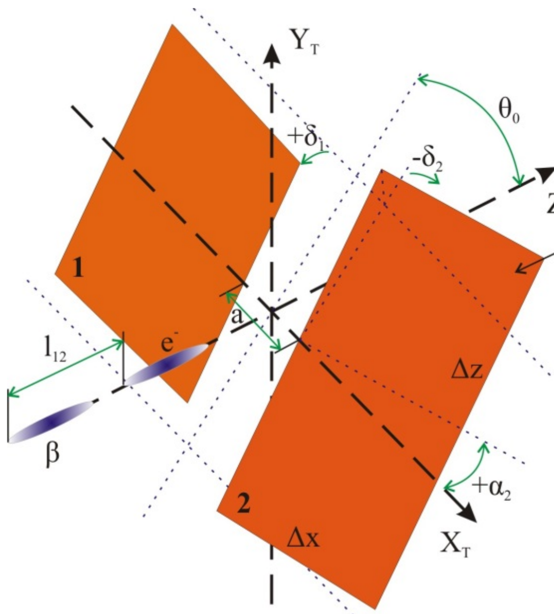

Figure 2: The principal scheme of the DR target with angle notation.

Table 1: Simulation Input Parameters

Beam energy	8.25 MeV ($\gamma \approx 16$)
Micro-bunch length	100 fs (30 μm)
Micro-bunch spacing	1 ps (300 μm)
Radiation wavelength range	0.01 – 3.0 mm (step 5 μm)
Target slit width	2 mm
Target-to-detector distance	700 mm
Target dimensions (Δz, Δx)	46×20 mm^2
Target tilt angle	π/4
Point of detector	(0, 0)
Interferograms step	20 μm

In the Table 1 all of simulation parameters are listed. Calculation was done for point-like detector without accounting for the detector aperture and sensitivity. One may note from the target-to-detector distance value the radiation observation takes place in the far-field zone. Detector (radiation observation point) is located in the direction of the mirror reflection relative to the target plane (angle $2\theta_0$ to "Z" axis). The quantities Δz, Δx are the plates dimensions along "Z" and "X" axis respectively (see at the Fig. 2).

RESULTS AND DISCUSSION

Bunch Form Influence

In Fig. 3 the form-factor curves for 1 bunch are shown for length σ_z = 0.03 mm (gaussian) and 0.09 mm (non-gaussian).

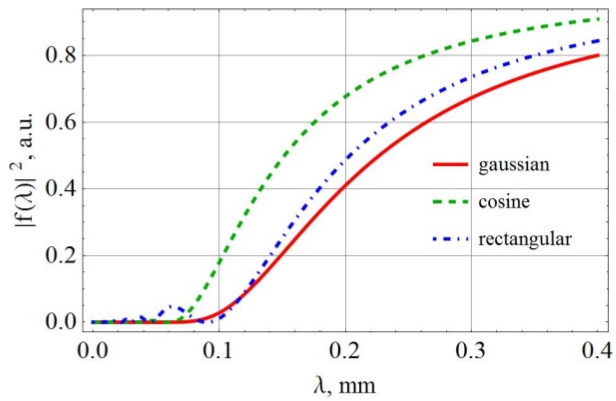

Figure 3: The bunch form-factor curve: gaussian profile – solid line, cosine profile – dashed line and rectangular profile – dot-dashed line.

In Fig. 4 the calculated interferograms are shown for the same electron distributions but different (1 and 4) bunches in the micro-train. One may see the interferograms shapes are very close to each other due to the similarity of the form-factors. For this reason we cannot directly derive bunch profile information from interferogram measurements for given parameters. For this purpose the use of reconstruction algorithm is still needed.

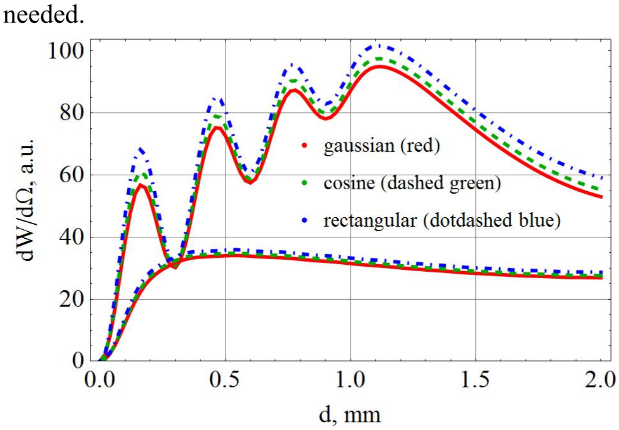

Figure 4: The calculated double DR interferograms for single bunch (lower) and 4-bunch micro-train (upper) with different longitudinal bunch profiles (same as Fig. 3).

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"δ" Angle Inaccuracy

On Fig. 5 the calculated interferograms for micro-train with 1, 2 and 4 bunches with inaccuracy δ_2 equal to $-1/\gamma \sim 3.58$ deg (0.0625 rad) are shown. From this plot it is clear that the interferogram central minimum becomes not a zero and a clear micro-train structure picture becomes almost indefinite. This statement is confirmed by additional calculations in case if $\delta_1 \neq -\delta_2$ with radiation observation in the mirror reflection direction. If $\delta_1 = -\delta_2$ it allow us to say that central minimum will be zero. For angle difference $\delta_1 - \delta_2$ of the order of $2/\gamma$ or more, practically there is no interference pattern between two radiation cones.

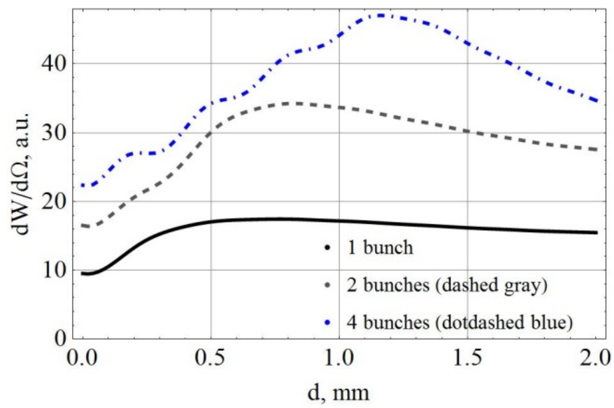

Figure 5: The calculated double DR interferograms for micro-train, $\delta_2 = -1/\gamma$.

"α" Angle Inaccuracy

On Fig. 6 the calculated interferograms for micro-train with 1, 2 and 4 bunches with inaccuracy α_2 are shown.

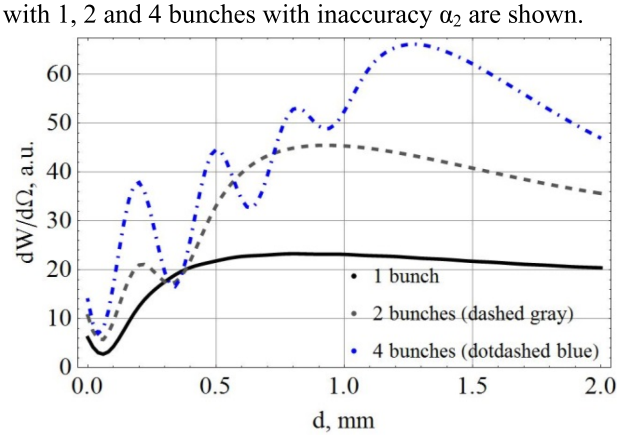

Figure 6: The calculated double DR interferograms for micro-train, $\alpha_2 = -1/\gamma$.

From this plot we can conclude that the interferogram central minimum is shifted but the amount of displacement is less than for the "δ" angle inaccuracy case. This shift is approximately equal to the value $sin\alpha_2 \cdot \Delta x/2$ what can be understood from geometrical considerations. From above one may conclude that the "α" angle inaccuracy is less distorting for the picture of micro-train structure reconstruction from the interferogram shape.

CONCLUSION

We investigated double DR target preparation accuracy requirements in order to minimize measurements uncertainties and increase interferometer resolution.

We managed to fulfill some of the items of the previously scheduled plan concerning to bunch form influence and angles inaccuracies. However an additional investigation should be continued.

We can conclude that such diagnostics using DDRT interferometry can be applied to determine the bunch length and micro-train spatial structure. The interferogram shapes weakly sensitive to the electron bunch form for given parameters. Electron bunch distribution can be obtained through application of the additional bunch profile reconstruction algorithm to measured interferogram.

As it was shown adjustment of "δ" angle is more strongly, in comparison to "α" angle, affects the interferogram shapes, therefore it's adjustment should be more precise.

Following to the calculation results we may conclude that angle adjustment must be of the order from 0.1 to 0.5 of γ^{-1} ($0.1\gamma^{-1}$ is equal to 0.36 deg for 8.25 MeV which technically possible to achieve).

Cross-check measurements with a deflecting cavity and THz Michelson interferometer [6] is scheduled at KEK LUCX facility. The double diffraction radiation target interferometry for the non-invasive determination of the bunch spacing could be considered as a robust diagnostics tool for modern accelerators and compact THz sources.

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