

MEASUREMENT OF SUB-PICOSECOND BUNCH LENGTH WITH THE INTERFEROMETRY FROM DOUBLE DIFFRACTION RADIATION TARGET*

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Abstract

Reliable and precise methods for non-invasive diagnostics of sub-picosecond electron bunches are required for new accelerator facilities (FEL, LWFA, et al.). Measurements of spectral characteristics of coherent radiation generated by such bunches using interferometer allow to determine a bunch length [1].

Here we present a compare experimental study between the measurement from the double diffraction radiation target interferometry and the measurement from the Michelson interferometer.

INTRODUCTION

Non-invasive methods of the sub-picosecond bunch length diagnostics are very important nowadays for such accelerator facilities as free electron lasers with typical bunch lengths of some hundreds of femtoseconds.

One of the ways to measure the electron bunch length is based on coherent radiation that is generated at wavelengths comparable to, or longer than, the bunch length, when all electrons in the bunch irradiate more or less in phase. The intensity of coherent radiation is proportional to the square of the bunch population. The spectral distribution of the coherent radiation contains information about the electron bunch distribution. Coherent diffraction radiation (CDR) is suggested as the mechanisms for coherent radiation generation due to their non-invasive nature.

DR appears when a charged particle moves rectilinearly in a vacuum in the vicinity of a medium. If the particle passes through a slit between two semi planes, it induces time-varying currents on both semi planes. These currents generate radiation. Two cones propagate in the direction of specular reflection producing an interference pattern.

The interference pattern obtained by two diffraction radiation beams from two shifted plates (double DR target) may be used instead an interferometer [2]. Recently, the coherent DR interferometry scheme was established [3] on the femtosecond accelerator facility at SINAP [4, 5].

* Work supported by the joint Russian-Chinese grant (RFBR No. 11-02-91177 and NSFC No. 11111120065) and partially by the Program of Russian Ministry of Education and Science “Nauka” and Chinese NSFC grant No. 11175240.

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EXPERIMENTAL SETUP

Our experimental equipments were consisted of a linear accelerator, a vacuum chamber with targets driven by motion-control system, a Michelson interferometer and a detector.

Accelerator

The accelerator providing femtosecond electron bunch facility consists of an S-band thermionic cathode rf-gun, an alpha magnet and a SLAC-type accelerating tube. The electron beam emerges from an APS type 1.6 cell $\pi/2$ mode thermionic rf-gun. After pre-accelerated at the rf-gun, the electron beam is transported to the alpha-magnet via a beamline consisting of the focusing, steering, scraping and beam monitoring components. The alpha-magnet is used to compress the electron beam from a few hundreds of ps to few hundreds of fs in longitudinal length. A SLAC-type accelerating tube is used to accelerate the electron beam up to high energy to minimize the lengthening force in the drift space. The design parameters of electron beam are listed in Table 1.

Table 1: Parameters of Electron Beam

Beam energy	20 – 30 MeV
Beam charge	0.068 nC
Normalized emittance	~ 10 mm·mrad
Macro-bunch repetition frequency	3.125 – 12.5 Hz
Micro-bunch repetition frequency	2856.2 MHz
Macro-bunch duration	2 – 3 μ s
Micro-bunch duration (FWHM)	0.3 – 3 ps

Interferometer

To measure the interferograms of the coherent diffraction radiation from ordinary DR target the typical Michelson interferometer was employed (see in Fig. 1). The interferometer consists of a beam splitter, which is made from a 2- μ m-thick nitrocellulose and comes with a metallic coating, providing consistent 30% reflection and 30% transmission over a very wide bandwidth, a stationary Au-coated hollow reflector mirror, a moving Au-coated hollow reflector stepped by remote control system capable of sub-micron steps, and a off-axis parabolic mirror that focus the re-combined light into the a pyroelectric detector.

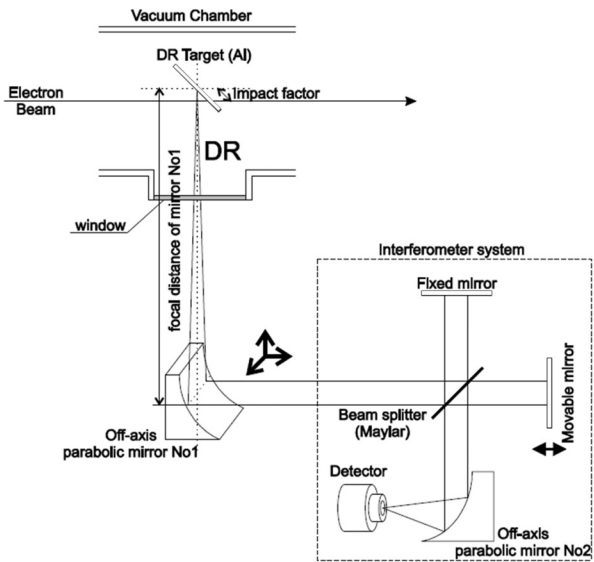


Figure 1: The experimental setup and the scheme of the interferometer.

Detector

To detect CDR a room temperature broadband LiTaO₃ pyroelectric detector SPI-D-62 THZ (Gentec-EO) was applied with the aperture diameter 5 mm which are optimized for use in our case. Other detector parameters are presented in Table 2.

Table 2: Detector Parameters

Sensitivity range	0.01 – 3 mm.
Response	150 kV/W
NEP	$0.4 \times 10^{-9} \text{ W}/(\text{Hz})^{1/2}$
Average power (max)	200 mW

In Fig. 2 the curve of detector sensitivity from specification is shown which was used in simulation.

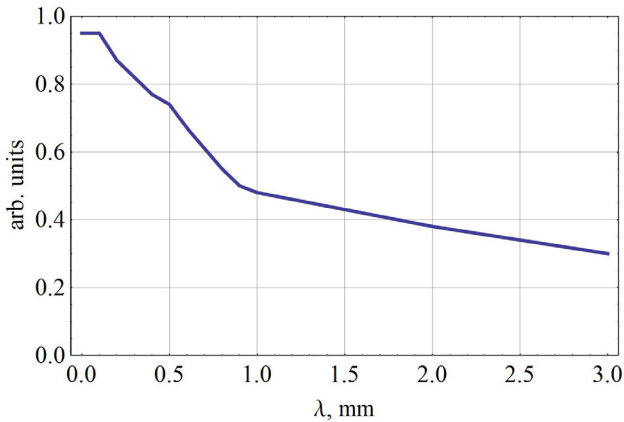


Figure 2: The curve of detector sensitivity.

Target

The DR target was consisted of two plates (with sizes $46 \times 20 \text{ mm}^2$) made from the $2 \mu\text{m}$ aluminum foil covered on the 0.3 mm polyamide film. Both plates were fixed on the holder with a possibility to move one plate relative other one along the beam direction with a step less than $16 \mu\text{m}$. During such a movement we measured coherent DR intensity for each position (interferogram).

In Fig. 3 the side view of doubled DR target is shown which illustrate the location of the two parallel plates relative to each other when they are shifted along beam to a distance d , $\theta_0 = 45^\circ$ is the tilt angle to the beam trajectory, β is the particles speed.

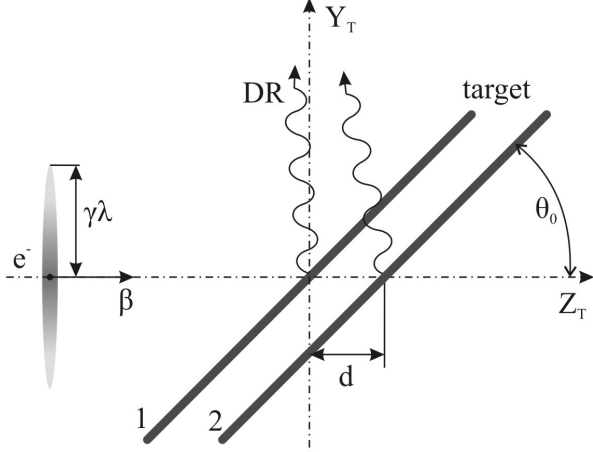


Figure 3: The shifted two plates of DR target.

RESULTS

First we measured the interferogram by applying the Michelson system with changing the position of the movable mirror. This interferogram was measured from the coherent diffraction radiation of one plate (ordinary DR target), when another plate was moved aside. In Fig. 4 the typical time domain interferogram from Michelson interferometer is depicted. The base of interferogram is equal to $0.249 \mu\text{W}$.

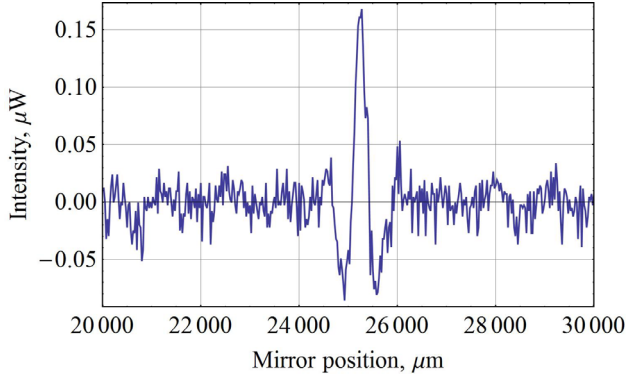


Figure 4: The typical Michelson interferogram.

Then we measured the interferogram using the coherent diffraction radiation interferometry. In Fig. 5, part of the whole interferogram measured in experiment is

presented in distance domain. In conducted experiment we could to get the interferogram only in time domain. In order to compare the calculated and experimental distribution and moreover to have a possibility to use the approach [6] for estimating the bunch length from CDR interferometry the time domain interferogram was transformed to distance domain. Knowing the speed one plate to other 100 $\mu\text{m/s}$ and macropulse repetition rate 6.25 Hz of the accelerator the 16- μm -step value between two points of experimental interferogram was received. Also the distribution minimum was shifted to the 0 of the horizontal axis and cut to the interval (-5; 5) like in the further simulation.

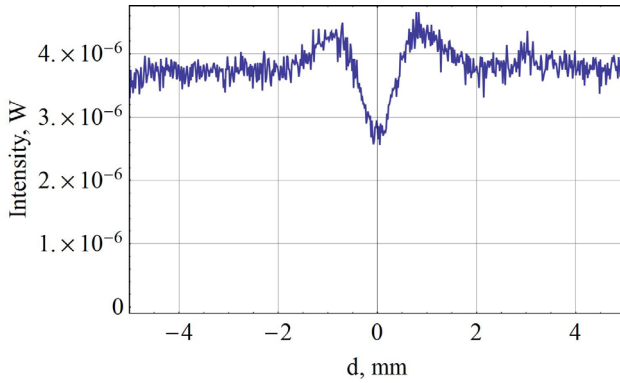


Figure 5: The modified experimental interferogram.

The interferogram in Fig. 5 was measured when the movable mirror in the Michelson interferometer was placed in the centre of interferogram on Fig. 4.

Table 3: Simulation Parameters

Beam energy	$E = 21 \text{ MeV}$
Bunch length	$\sigma_{\text{RMS}} = 0.2 \text{ mm}$
Wavelength range of simulation	$0.1 - 3 \text{ mm}$
Target slit	$a = 10 \text{ mm}$
Distance from the target centre to the centre of detector	$L = 260 \text{ mm}$

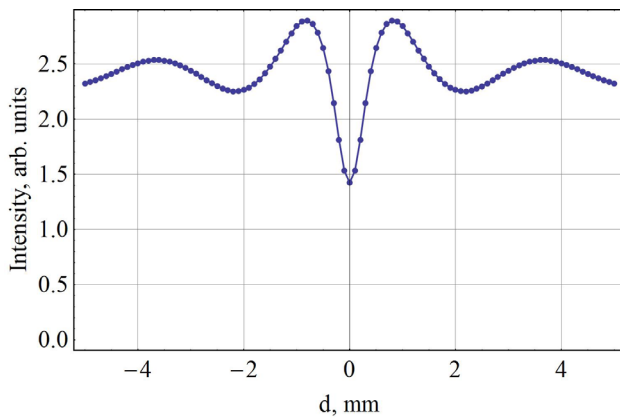


Figure 6: The simulated interferogram.

Finally the simulation was carried out for parameters of experiment. The parameters are listed in Table 3.

In Fig. 6 below the simulation of the interferogram for value of the bunch length equal to 0.2 mm averaged on the 25 points of detector is shown.

These 25 points on the detector surface are located along and across relative to motion of the beam with the same step from each other one. Above mentioned average was done to account for the detector aperture. The developed model [7] also takes the detector sensitivity into account in present case.

DISCUSSION

Applying the algorithm for spectra reconstruction described in [8], we have obtained the spectrum from Michelson interferogram (see in Fig. 7 red solid curve). The analysis of this spectrum gives the estimation bunch length about 0.19 mm that equal to 660 fs. The simulation of such spectrum using the above mentioned model is presented on the same Fig. 7 (blue dashed curve). This simple simulation is performed without taking into account the aperture and the sensitivity of detector with parameters like in Table 3, but with impact-factor 5 mm.

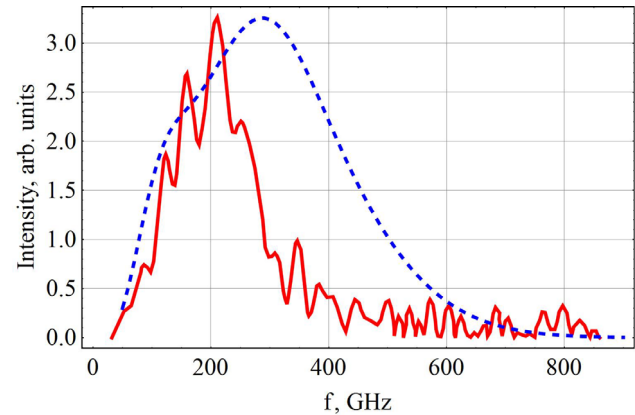


Figure 7: The spectrum from Michelson interferogram and calculated spectrum.

Moreover we can apply another technique because the main part of information about the bunch length is contained in the first oscillation of the interferogram. Therefore we may try to build a criterion for the bunch length estimation using this part of interferogram. If we define the interferogram function as $S(d)$, then the simplest criterion may be represented using the dimension theory [9] as

$$\sigma_{\text{RMS}} = f(x),$$

where

$$x = \left((S(d) - S(0)) / \frac{\delta S(d)}{\delta d} \right) \Big|_{d=d_{\text{max}}},$$

d_{max} is the value of variable d in the point of maximal $\frac{\delta S(d)}{\delta d}$, σ_{RMS} is the bunch length in Gaussian approximation of the longitudinal distribution of electrons

in bunch, the function $f(x)$ is yet undefined. For definition of this function we calculated the dependence $x(\sigma_{RMS})$ from theoretical curves of interferogram in Gaussian approximation of the longitudinal distribution of electrons. Finally with a good accuracy was obtained $\sigma_{RMS} = x$.

Applying the described approach for the experimental interferogram (Fig. 5) the bunch length was estimated about 0.2 mm. For the simulated interferogram (Fig. 6) was obtained the value about 0.248 mm. The difference of these values may be explained by a not enough alignment of the double DR target.

It is clearly seen a good agreement all of results from two techniques which confirms the ability of the proposed technique for non-invasive bunch length measurements in the sub-picosecond range without a complicated scheme like Michelson interferometer or similar.

CONCLUSION

The first measurement of the sub-picosecond electron bunch length was carried out using coherent diffraction radiation interferometry (non-invasive beam diagnostics technique).

From the measured interferogram the RMS bunch length was found to be about 660 femtosecond, which confirms the ability of the proposed technique for non-invasive bunch length measurements in the sub-picosecond range.

The developed technique doesn't need any complicate interferometer and additional optics elements.

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