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TOWARD THz COHERENT UNDULATOR RADIATION EXPERIMENT WITH A COMBINATION OF VELOCITY BUNCHINGS

Yoske Sumitomo*, Takeshi Sakai, Ken Hayakawa, Yasushi Hayakawa, Kyoko Nogami, Toshinari Tanaka, College of Science and Technology, Nihon University, Funabashi, Chiba, Japan
Norihiro Sei, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

Abstract

We launched a research program to generate the terahertz (THz) coherent undulator radiations, following the proposal of the "combination of velocity bunchings". The combination of velocity bunchings is an efficient way of bunch compression allowing a range of energy choices, in other words, a range of quasi-monochromatic radiation wavelengths generated at the undulator. In addition to the exisiting wide band THz light sources by the coherent edge and transition radiations currently available at Nihon Univ., the development of a high peak-power and quasi-monochromatic coherent radiation should accelerate the activities including the material science related with the THz bands. Here, we illustrate the program and report the current status of the experiment.

INTRODUCTION

Recently, there have been lots of significant developments in the research areas related with lights of THz bands. The THz bands are located between radio waves and infra-red frequencies and hence the expectations toward their industrial applications are tremendously high. As illustrated in [1, 2], their importance and significant competition can be seen as the exponential growth of the number of recent research papers regarding THz sciences.

The state-of-the-art technologies of intense THz radiations open up a new direction of researches, that provide a versatile handle for control of various degrees of freedom, for instance, crystal lattice vibrations, molecule rotations, spin precessions, and electron accelerations (see [3] for detail). The possible extensive interactions with matters include multiple transitions and large-amplitude coherent motions in resonant modes, and the deposition of energies into nonresonant degrees of freedom, and also highly nonlinear collective responses. Besides the importance of intense THz fields, it is worth commenting that the recent technologies of accelerator enable to control electron motions within sub pico-seconds easily so as to generate intense coherent THz radiations.

We have developed the light sources at THz bands in Nihon Univ. [4, 5]. Using the transition radiations and edge radiations, we generate the broadband THz lights ranging from 0.1 - 2.5 THz, that are supplied for user applications. In addition to the available broadband radiations, we are making development of quasi-monochromatic intense THz light sources generated by coherent undulator radiations. We employ a scheme of efficient bunch compression, namely the "combination of velocity bunchings" proposed in [6]. An advantage against the standard velocity bunching is that we have a range of electron energy choices corresponding to the choices of undulator radiation wavelength thanks to the degree of freedom of combinations, although the energy choice is limited for the standard velocity bunching. See [7] for the other development of the coherent undulator radiations regarding the standard velocity bunching. In this paper, we will review the project briefly, and report the current status and the future plan of experiment.

* sumitomo.yoske@nihon-u.ac.jp

COMBINATION OF VELOCITY BUNCHINGS

Let us start with a brief introduction of "combination of velocity bunchings" proposed in [6]. The standard velocity bunching is the well-known bunch compression method achieved by having a velocity difference between the head and tail of electron bunch. We see easily that this bunch compression works well when the energy of electrons is not high to have an enough velocity difference. However, when the electron energy is too low, the serious space-charge force disturbs the bunch compression. Hence, the velocity bunching is known to work well at around few MeV scale of electron energies.

We use the acceleration tubes adopting travelling wave accelerations of electrons under the assumption that electrons run almost at speed of lights. Since the electrons at few MeV are slightly slower than the speed of lights, accelerations of each electron can be different as a result of integration along the tube, especially, the difference can be larger between the head and tail of bunch structure at a suitable phase of acceleration. For a better understanding of the standard velocity bunching, we illustrate a phase scan simulation result of a travelling wave acceleration against the bunch width and its mean energy in Fig. 1, assuming an initial condition. Here we use ASTRA code [8] for the simulation. We see that the energy after the acceleration is limited at the phase of most bunch compression.

In the combination of velocity bunchings, we introduce additional degrees of freedom to alleviate the severe condition of energy choice accompanied by the bunch compression. Note that the electron energy is an important parameter determining the wavelength of undulator radiations, and its degree of freedom is a key parameter for the development of variable quasi-monochromatic light sources. Here we

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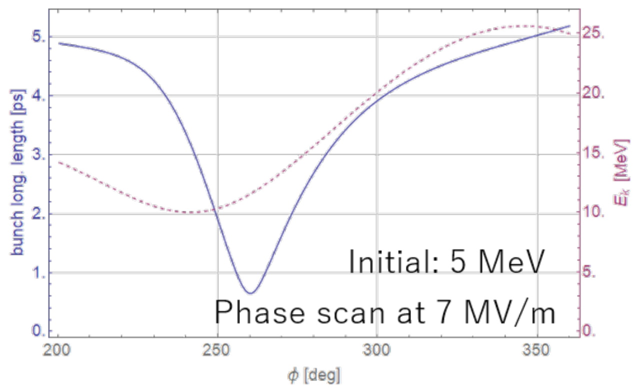

Figure 1: An example of phase scan simulation of a travelling wave acceleration under an initial condition. The quantities shown on the vertical axis are obtained at the exit of acceleration tube.

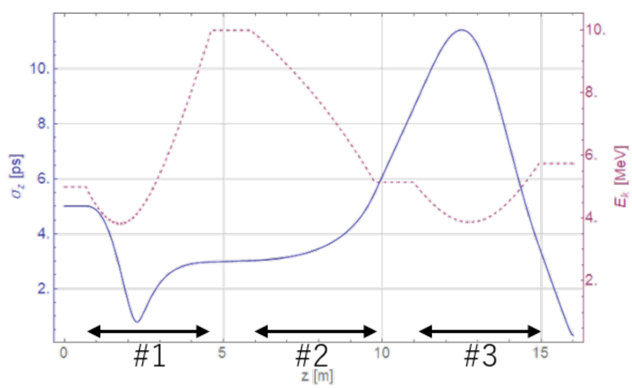

Figure 2: An example of combination of velocity bunchings shown in [6]. We added the section information of each acceleration tube.

simply illustrate a simulation example of the combination of velocity bunchings in Fig. 2, following the three acceleration tubes structure in Nihon Univ., where not only accelerations but also decelerations are taken into account. We see that the bunch compression is more effective after the combination. Although this is just an example for the illustration, there are other examples suggesting enough bunch compressions for THz coherent radiations, but at different energies.

INSTALLATION

To demonstrate the proposed scheme of bunch compression as well as the realization of coherent undulator radiations, we have installed several components at our facility. Following the parameters of the existing undulator that is an component of the mid-IR oscillator FEL and we use also for this project, the electron energy should be around 10 MeV to generate coherent undulator radiations at THz wavelengths. Since the radiations generated from such the low energy electrons emit at a wide angle, the transport and extraction of the radiations are concerns to be handled. Hence we installed an extraction chamber right after the undulator and replaced the undulator duct to be rectangular one for a better transport, at least on one transverse direction even when the undulator gap was minimized. We use a gold coated concave mirror installed inside the extraction chamber, that has a hole at the center to ensure the coexistence with the electron beam penetration. We also installed three radiation monitors around the undulator, consisting of CsI (Tl) scintillators and photomultipliers to avoid unexpected radiation damages to the undulator Nd magnets during the operation of electron beam. We have to change the phases of accelerations drastically to find the condition for the combination of velocity bunchings. We summarize the installations on a schematic of our accelerator facility in Fig. 3.

EXPERIMENTAL STATUS

The undulator beam line at our facility is the beam line designed to generate mid-IR fs lasers ranging from 1 µm to 6 µm as the oscillator FEL, and we had no experience to achieve the lower energy electron beam transports before this project. Hence, we started by decreasing the beam energy with a set of existing parameters for mid-IR radiations where the beam energy was above 50 MeV, otherwise it was difficult to ensure to minimize the unexpected high-energy radiations. Note that we have no monitors causing the beam breakup to avoid the high-energy radiation damages to the detectors and the components. Due to the 20 µs accelerations with the thermionic electron emissions, the handling of radiation damages is a primary issue at our facility.

We had careful operations of beam transport during lowering the beam energy with the help of the radiation monitors installed around the undulator. So far, the beam energy we realized reaches 13.5 MeV, that is very close to the initial target energy for THz coherent radiations. However, due to the campus lockdown and some consequent serious troubles related with the absence of long-term maintenance, unfortunately our beam time was quite limited. Although we faced the slight delay in the progress, it is worth noting that such the low energy beam transport around 30 m at our facility was not ever achieved until this trial, where only higher energy transports were assumed at the time of construction.

DISCUSSION

We illustrated the current experimental status toward the realization of THz coherent undulator radiations. The radiations generated from the low energy electrons have a wide spread angle, and hence we need the installation of extraction chamber right after the undulator and the replacement with the rectangular undulator duct helping the radiation transports. The radiation monitors installed around the undulator alleviated the concern of undulator demagnetization during the drastic beam operations. Although the available beam time was quite limited, we achieved the successful 13.5 MeV beam transport that was not ever realized and is close to the initial target energy for the generation of THz coherent undulator radiations.

The goal of this project includes the experimental verification of the efficient bunch compression proposal, namely,

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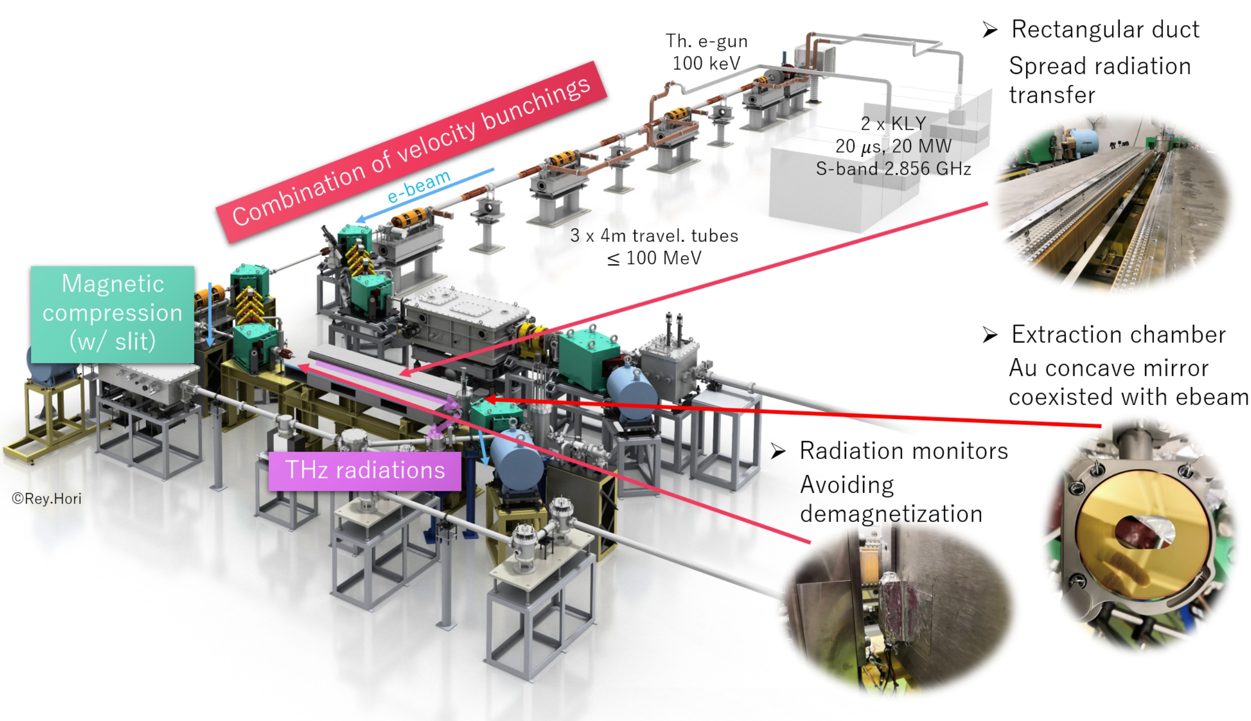

Figure 3: An overview of our facility and the installations for the project.

the "combination of velocity bunchings". In this bunch compression scheme, the phase status of the travelling wave accelerations is the most important parameter to have a better combination. Although we can not see the beam energy achieved after each acceleration tube directly due to the space limitation of our facility, the RF output power is monitored at each exit of the tubes. The information of the output power can be used to understand how large the beam is accelerated or decelerated. Together with the simulation results as shown in Fig. 2, we are able to perform a better beam operation with the suitable phase control for the realization of the combination of velocity bunchings.

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