ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW037

SYSTEMATIC MEASUREMENTS OF THE COHERENT THz SPECTRA BY MAGNETIC BUNCH COMPRESSION AT THE COMPACT ERL

Miho Shimada*, Yosuke Honda, Tsukasa Miyajima, Takashi Obina,
Norio Nakamura, Takashi Uchiyama, Ryukou Katoh
High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan
Takahiro Hotei
SOKENDAI, Tsukuba, Ibaraki, Japan

Abstract

Short electron bunch beam is one of the key elements of a Free Electron Laser (FEL) or intense THz coherent light source. The Energy Recovery Linac (ERL) has the strong advantage of operation of such an electron bunch at high repetition rate and is expected to increase the photon flux. At the Compact ERL in KEK site, we have demonstrated the magnetic bunch compression at the 180-degree return arc and measured the THz spectra of the Coherent Transition Radiation (CTR). This paper reports the revamped THz beamline and the improvement of the beam tuning as well as the systematic measurements of the THz spectra by magnetic bunch compression.

INTRODUCTION

Energy recovery linac (ERL) based on CW superconducting linac has the potential to realize high-quality beam satisfying simultaneously low transverse emittance, short bunch length, and high average beam current. Such a high-quality beam is expected for a free electron laser, coherent THz radiation, and short pulse X-ray. The compact ERL was constructed as the test facility at KEK site. The beam commissioning has been intermittently performed for several years to develop the scientific and industrial application. We systematically performed the measurement of the bunch compression.

BUNCH COMPRESSION AT THE COMPACT ERL

Layout and Optics Ttuning

To avoid the emittance growth due to the space charge effect and coherent synchrotron radiation (CSR) wake at the low electron energy, the bunch length is compressed after the full acceleration.

The bunch compression is based on the following equation.

$$\Delta z = R_{56}\delta + T_{566}\delta^2 + \cdots \quad (1)$$

where Δz is the change in the longitudinal position, $\delta = \Delta p/p_0$ is a momentum deviation, R_{56} and T_{566} are the element of the transfer matrix. The slope of the longitudinal phase space created by off cres can be changed at the following non-zero R_{56} arc section.

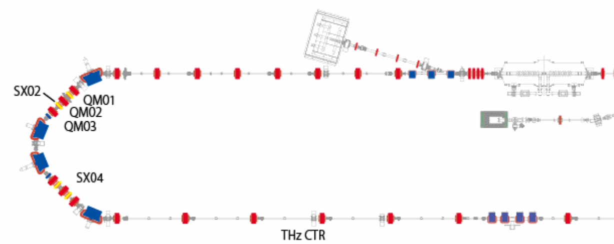

Figure 1: Layout of the main linac and the arc section of the compact ERL.

The schematic and layout of the bunch compression are shown in Fig. 1. The full beam energy at the recirculation loop is 17.9 MeV. The RF phase is shifted by an only downstream second cavity of the main linac. The beam energy and its energy spread are measured at the screen monitor just behind the first 45-degree bending magnet. Although it is composed of four bending magnets, the optics is similar to a called triple bend achromat (TBA). The screen monitor and BPM are placed at the center of the arc section. Quadrupole triplets and sextupole magnets control R_{56} and T_{566}, respectively. In the cERL layout, the symmetric linear optics enables us to estimate R_{56} from the dispersion function at the center of the arc section η_{xc}, $R_{56} = 1.41\eta_{xc} - 0.34$. According to the design optics, when the change in the focus strength of the QM01, QM02 and QM03 from the achromat and isochronous optics is approximately maintained at the ratio of -1:2:0, R_{56} can be controlled with keeping the achromat condition. It is used as a tuning knob of the triplet quadrupole in the arc section.

Measurement System of THz Coherent Transition Radiation

Coherent synchrotron radiation (CSR) from a bending magnet is non-destructive for the electron beam, therefore the bunch length estimation is possible even high average beam current operation. However, the bunch length varies in the bending magnet in the bunch compression. Therefore the spectra of the coherent THz radiation (CTR) is utilized to estimate the bunch length at the south straight section. The electron beam is operated in low current during the CTR measurement destructing the electron beam.

The measurement system of the interferometer for CTR is shown in Fig. 2 [1]. The CTR spectrum is measured with a Si bolometer: the CTR path can be switched to the narrowband

* miho.shimada@kek.jp

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW037

diode detectors with a movable mirror. The window material is the crystal quartz to cover the higher frequency of the THz region. In addition, the THz transport line and the bolometer are housed in a vinyl hatch filled with dry air to avoid the water absorption. A movable filter holder is settled in the front of the bolometer to insert the 10% bandpass filters at the center frequency of 0.5, 1.0 and 1.5 THz.

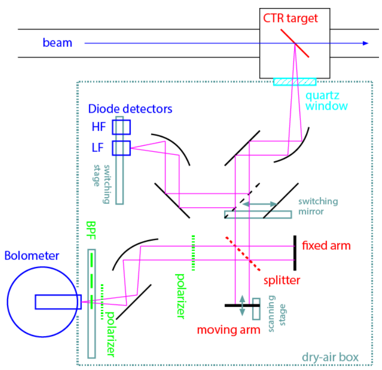

Figure 2: Setup of the THz CTR measurement system.

RESULTS OF OPTICS TUNING AND THZ MEASUREMENT

Tuning for Off Crest Acceleration

The off-crest acceleration is performed by varying the accelerating phase of the second (last) cavity of the main linac. The average beam energy and energy spread are measured with varying the phase at the screen monitor just behind the 45-degree bending magnet shown in Fig. 1. In this bunch compression beam experiment, the RF phase at the minimum energy spread is corresponding to that at the maximum average beam energy. It means the slope of the longitudinal phase space is negligible. We call it the on-crest acceleration. To maintain the beam energy of the recirculation loop at constant (17.9 MeV) during this bunch compression, the accelerating field of the second cavity is slightly increased for off-crest acceleration.

Achromat and R_{56} Tuning

The dispersion function is measured with BPM by decreasing the beam energy by 1%. For optics tuning, the focus strengths of the triplet quadrupoles are controlled symmetrically using the tuning knob described above. The symmetrical optics enables us to estimate R_{56} of the arc from the dispersion function. We, however, experimentally found the appropriate ratio of the tuning knob for the achromat optics and R_{56} control because the dispersion function is slightly different from the design optics. The ratio is 1:0:0 and -1:1.4:0, respectively.

SX and Vertical Dispersion

Two horizontal sextupole magnets are installed to control T_{566} shown in eq. 1. For bunch compression less than a few hundred fs, it is important to compensate the curvature of the longitudinal phase space caused by the 1.3 GHz RF [2]. The sextupole magnets are turned off during measurement of the dispersion function. The sextupole magnets are equipped with correction coils to suppress the unexpected vertical dispersion function. The beam orbit is adjusted to transport through the center of the quadrupole and the sextupole magnets, in which the beam position is fixed even if the focus strength is changed.

Optics Tuning for R_{56} and T_{566} Optimization

The transverse beam size is focused smaller than 300 μm at the CTR target not to decrease the THz radiation. The bunch length is assumed to be minimized when the THz CTR intensity is maximized. Figure 3 shows the dependency of the CTR intensity on R_{56} and the sextupole magnet. The off-crest phase is +12 deg. The value of R_{56} of the arc and the sextupole magnet are iteratively optimized to maximize the THz CTR intensity.

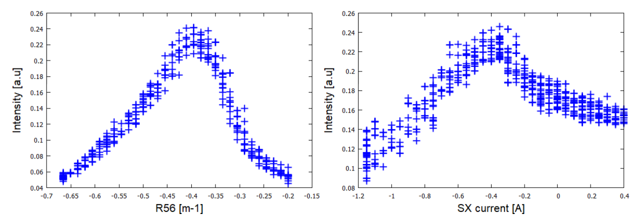

Figure 3: THz CTR intensity measured by the diode detector during the scan of R_{56} and T_{566}.

Crosscheck of THz Spectrometer with Bandpass Filter

After maximizing the CTR intensity, the THz spectrometer is evaluated with the several bandpass filters at the center frequency are 0.5 THz, 1.0 THz, and 1.5 THz. Because of 10% bandwidth, the interferometer response is sinusoidal. The THz spectra obtained by Fourier transform is shown in Fig. 4. The peaks of the THz spectra agree well with the bandpass filter. We assumed the cutoff frequency of the CTR measurement system is close to 1 THz from the peak.

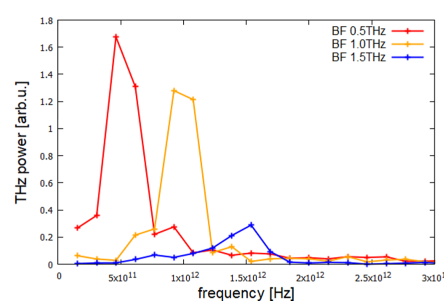

Figure 4: Spectra of bandpass filters measured by the interferometer.

Bunch Length Estimation

We measured the bunch length at the off-crest phase of +12 deg. An example of the interferometer response is shown

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW037

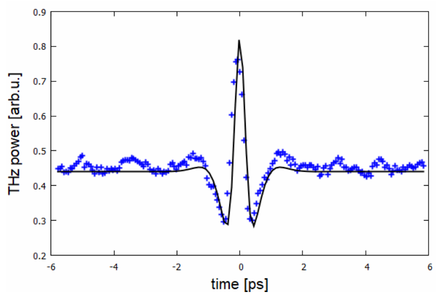

Figure 5: Example of the interference response and its fitting curve.

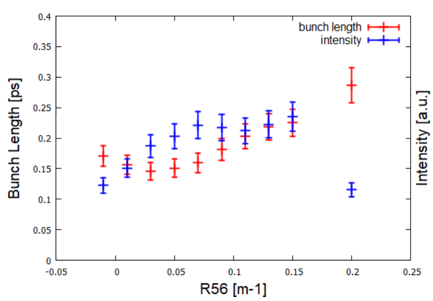

Figure 6: The maximum intensity of CTR and the estimated rms bunch length with varying R_{56}.

in Fig. 5. When the longitudinal bunch shape can be approximated to a Gaussian distribution, the rms bunch length can be estimated by the simple equation from the interferometer response [3]. To investigate how the rms bunch length varies with the liner optics of the arc, the maximum intensity of CTR response and the rms bunch length are scanned with R_{56} as shown in Fig. 6. The minimum bunch length is 150 fs, which has the estimation error of a few ten %. The value of R_{56} of the maximum intensity is different from that of the minimum bunch length. It is considered to be caused by the facts that the longitudinal bunch profile is different from the Gaussian shape.

Charge Dependency

Figure 7 shows the electron bunch charge dependency of the maximum intensity of CTR and the bunch length estimated by the interferometer results. The intensity increase quadratically with the bunch charge. It shows that the THz radiation is coherent. Although the collective effect on the beam such as the space charge effect and the CSR wake depends on the bunch charge, the bunch length is almost constant.

Off-crest Phase Dependency

We survey the interferometer response at the off-crest phase from 0 deg to 24 deg. During this survey, the accelerating field is controlled for maintaining the constant recirculation beam energy, 17.9 MeV. The value of R_{56} and the sextupole magnet is optimized for +12 deg off-crest phase as described above. When the RF phase is shifted from the optimized one, the CTR intensity is decreased as shown in Fig. 8.

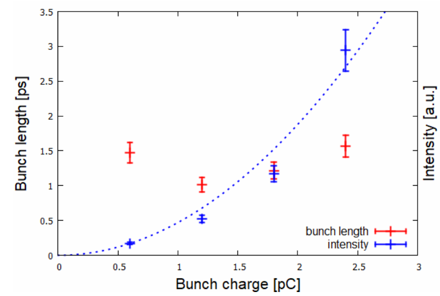

Figure 7: Electron charge dependency of the maximum intensty of CTR and the bunch length.

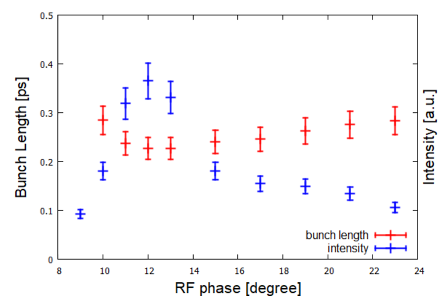

Figure 8: RF phase dependency of the maximum intensity of CTR and the bunch length.

CONCLUSION

We performed the systematic measurement of the bunch compression at the compact ERL. The measurement spectra of the THz interferometer is consistent with the bandpass filter. The THz radiation is confirmed to be coherent radiation. The minimum bunch length is 150 fs when the cutoff frequency is assumed to 1 THz. The bunch length is varied with R_{56} and the off-crest phase. The measurement results are expected to utilize for exploring shorter electron bunch.

ACKNOWLEDGEMENTS

We would like to thank the cERL development team for their support in regard to the beam operation. This work was partially supported by JSPS KAKENHI Grants No. 16H05991 and No. 18H03473, and by Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

REFERENCES

[1] Y. Honda *et al.*, *Nucl. Instrum. Methods* A 875 (2017) 156-164.

[2] M. Shimada *et al.*, "Bunch Compression at the Recirculation Loop of the Compact ERL", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 3008–3010. doi:10.18429/JACoW-IPAC2016-WEPOY010

[3] A. Murokh *et al.*, *Nucl. Instrum. Methods* A 410 (1998) 452-460.