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STATUS OF BEAM COMMISSIONING AT NanoTerasu

K.Ueshima*, T. Asaka, Y. Hosaka, K. Kan, N. Nishimori, S. Obara, QST, Miyagi, Japan
T. Aoki, K. Haga, A. Ihara, K. Ito, T. Iwashita, M. Kadowaki, H. Kobayashi, H. Kobayashi, R. Saida, H. Oikawa, K. Sakuraba, K. Sugimoto, S. Takahashi, T. Tsuchiyama, NAT Corporation, Japan
N. Adumi, T. Aoki, H. Dewa, T. Fujita, M. Kawase, A. Kiyomichi, T. Hamano, M. Masaki, C. Saji, S. Matsubara, K. Okada, T. Masuda,T. Taniuchi, Y. Taniuchi, T. Tomai, Y. Ueda, M. Shoji, C. Kondo, K. Yanagida, K. Fukami, N. Hosoda, M. Ishii, T. Itoga, E. Iwai, T. Magome, M. Oishi, T. Ohshima, T. Sakurai, H. Yamaguchi, T. Sugimoto, S. Takano, K. Tamura, T. Watanabe, JASRI, Hyogo, Japan
S. Inoue, H. Kumazawa, K. Moriya, K. Sakai, T. Seno, H. Sumitomo, R. Takesako, S. Tanaka, R. Yamamoto, K. Yokomachi, M. Yoshioka, SPring-8 Service Co.,Ltd, Hyogo, Japan
T. Inagaki, H. Maesaka, K. Soutome, S. Takahashi, T. Tanaka, T. Hara, T. Hiraiwa, S. Matsui, H. Tanaka, RIKEN SPring-8 Center, Hyogo, Japan

Abstract

NanoTerasu is a new 3 GeV compact light source constructed in Japan. The lattice structure is a type of multi-bend achromat with designed horizontal and vertical emittance values of 1.14 nm rad and 10 pm rad, respectively. A target stored beam current is set to 400 mA to provide a high coherence and highly brilliant light from extreme ultraviolet to tender X-ray range. The injector Linac commissioning was started in April 2023. After first 10 days, the beam energy successfully reached 3 GeV with the designed emittance. The storage ring commissioning was started on June 8th. We achieved the off-axis beam injection just adjusting beam injection trajectory from the beginning of the beam commissioning. As a result of the precise alignment of the magnets, the injected beam turned around 300 turns without the supply of RF power and the adjustment of the steering magnets on the first day of the commissioning. The stored beam current reached 300 mA with top-up beam injection in November 2023. The first user time operation was started with high reliability and high performance on April 9th 2024.

INTRODUCTION

The NanoTerasu is a compact 4th generation 3 GeV light source newly constructed in Sendai, Japan [1, 2]. The NanoTerasu construction was started in 2019. At the first phase, 10 beamlines were constructed. In total, 28 beamlines could be constructed.

The accelerator system of NanoTerasu consists of full energy injector Linac and storage ring (SR). The Linac system consists of 40 MeV pre-injector system and C-band accelerator system. The length of the Linac is only 110 m due to the high acceleration gradient of C-band accelerator. The pre-injector system consists of compact electron gun, 238 MHz acceleration cavity, 476 MHz sub-harmonic buncher (SHB) and S-band acceleration system as shown in Fig. 1. The compact thermionic electron-gun with the grid cathode is originally developed to produce low emittance electron beam with easy maintainability [3]. The injected beam charge can be adjusted using a collimator with a continuously variable iris size [4]. The C-band accelerator consists of 40 accelerating structures with 2 m length. The average acceleration gradient is about 37.5 MV/m. The 3 GeV C-band full-energy injector Linac enables the extension to the soft X-ray (SX) free electron laser in the future.

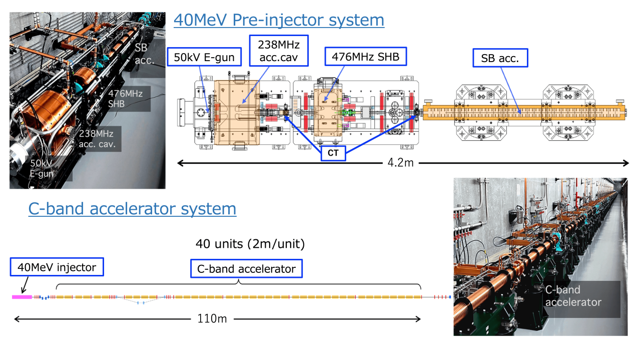

Figure 1: The layout of Linac system.

The SR circumference is 349 m and the natural emittance is 1.14 nm rad, which is realized by a 4 bend lattice as shown in Fig. 2. Four B-Q combined bending magnets, 10 quadrupole magnets and 10 sextupole magnets were installed in one unit cell. The SR consists of 16 cells in total. The new type of TM020 mode RF cavity with higher-order-mode dampers was developed [5]. In the beam injection point at SR, the in-vacuum off-axis beam injection system was installed for the stable top-up beam injection [6]. To measure the stored beam position, 7 BPMs were installed in one unit cell. In total 112 BPMs were used for monitoring the closed-orbit distortion (COD). A compact 3-pole wiggler with 1.27 T peak magnetic field and X-ray pinhole camera (XPC) [7] were used for monitoring the stored beam profile at the short straight section (SSS) as shown in Fig. 3. The designed horizontal and vertical beam size at SSS were 80 µm and 6 µm, respectively. Using hard X-rays with the peak energy of about 50 keV, the stored beam profile was monitored with about 5 µm resolution [8]. To suppress the transverse instability, the bunch-by-bunch feedback (BBF) system based on the iGp12 developed by Dimtel Inc., the 4-electrode stripline kicker and stripline BPM were installed.

* ueshima.kouta@qst.go.jp

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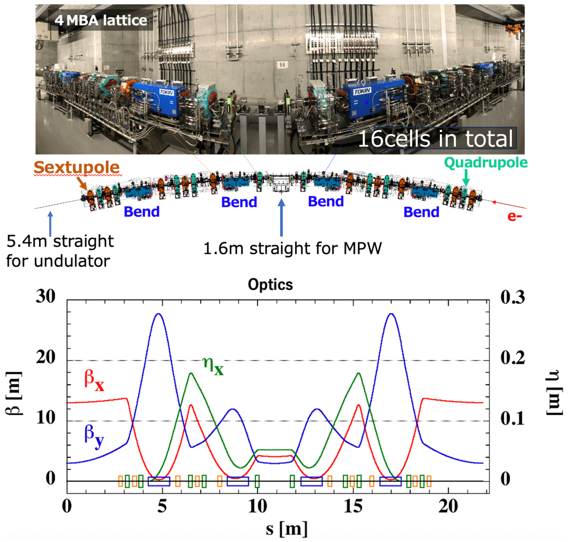

Figure 2: The magnets layout (top) and Lattice functions (bottom) in the one unit cell.

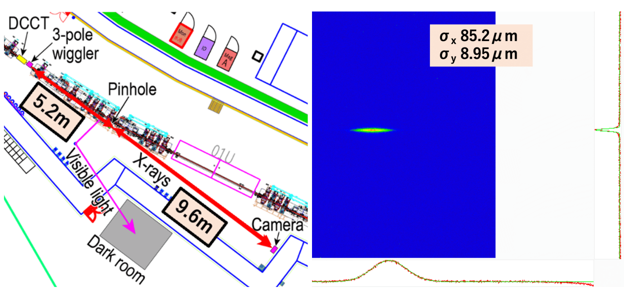

Figure 3: The layout of 3-pole wiggler and XPC (left). 160 mA stored beam profile with designed horizontal emittance (right).

BEAM COMMISSIONING

The beam commissioning timeline is summarized in Fig. 4.

Date	Event
2019	Start construction
Apr.17th 2023	Start Linac beam commissioning
Apr.27th	Confirm 3 GeV beam
Jun.8th	Start SR beam commissioning,turn around 300 turns w/o FTS
Jun.16th	First light observation of stored beam
Jul.7th	Stored beam size profile observation
Aug.1st	Start 24hr beam operation for vacuum baking
Aug.10th	Stored beam current reached 100mA with designed emittance
Sep.	Start ID commissioning
Dec.	First beam observation in experimental hall
Apr.9th 2024	Start First user operation
Apr.21st	Finish first user operation (user time ratio 99.4%)

Figure 4: The beam commissioning timeline.

Linac Commissioning

The Linac commissioning was started on April 17th in 2023. The 50 keV electron beam emitted from gridded thermionic electron-gun was immediately accelerated to 500 keV in the 238 MHz cavity. After that, 500 keV electron beam was bunch compressed in the 476 MHz SHB from 500 psec to 5 psec (FWHM). In the 2 m long S-band accelerator, the electron beam energy reached 40 MeV. The RF parameters of 238 MHz cavity and 476 MHz SHB were adjusted using the time-of-flight measurement between two CT monitors. The twiss parameters were measured using the quadrupole scan method. The low-level RF system based on MicroTCA.4 was used for controlling RF phase and amplitude precisely to produce 3 GeV electron beam with high stability and reproducibility. In addition, precise phase scan of the C-band accelerator was performed. Table 1 shows the preliminary results of the Linac commissioning. The energy spread and stability were measured using a screen monitor at first energy dispersive section after the end of C-band accelerator system.

Table 1: Required and Achieved Beam Parameters in Linac Commissioning

Beam parameters	Requirement	Measurement
Beam charge	0.3 nC	0.36 nC
Horizontal emittance	2.0 nm rad	1.04 nm rad
Vertical emittance	2.0 nm rad	1.84 nm rad
Beam energy	3 GeV	3 GeV
Beam charge stability	-	0.52%(RMS)
Energy spread	< 0.2%	0.043%(FWHM)
Energy stability	0.1%	0.057%

SR Commissioning

The SR beam commissioning was started on June 8th. The off-axis beam injection was achieved just adjusting the position and angle of injected beam. The injected beam turned around 300 turns without the supply of RF power on the first day of SR beam commissioning as shown in Fig. 5. Due to the precise alignment of the magnets using laser tracker, the first turn steering was not needed. The alignment accuracy of the magnets was within 50 µm. After the RF conditioning of SR RF cavity, the electron beam was stored in SR on June 16th. On the same day, the first light from the 3-pole wiggler was observed as shown in Fig. 5.

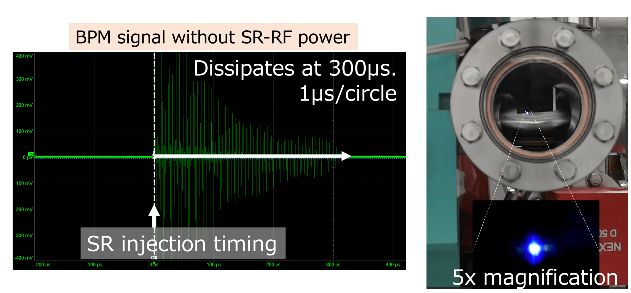

Figure 5: BPM signal when the injected beam completed about 300 turns without RF supply (left). First light of the stored beam (right).

Twenty four hours beam operation was started for vacuum conditioning on August 1st. The stored beam size monitored with the XPC was increased when the stored beam

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current reached about 10 mA due to the transverse instability. The parameters of horizontal and vertical BBF systems were adjusted to suppress the transverse instability. The horizontal and vertical fractional betatron tune values were monitored using BBF systems. The stored beam current reached more than 100 mA with designed emittance in August. Fig. 3 shows the stored beam profile with 160 mA observed with the XPC. The horizontal and vertical beam size were 85.17 µm and 8.95 µm, respectively.

The beam-based alignment (BBA) [9] of all BPMs was performed to adjust the beam optics parameters precisely. The BPM offset against the magnetic field center of the nearest quadrupole was measured within 10 µm accuracy. The stored beam current reached 300 mA in November. Fig. 6 shows the top-up beam injection operation with keeping stored beam current of 300 mA within 1.5 mA variation for 4 hours.

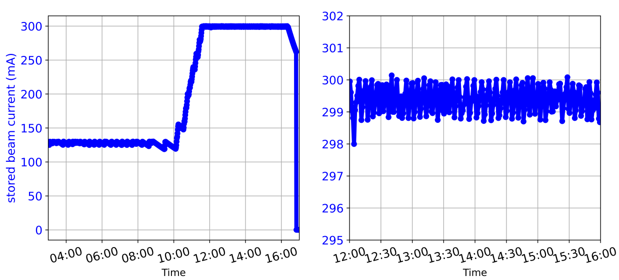

Figure 6: 300 mA top-up operation on Nov. 15th (left). The detail view in 300 mA operation period (right).

The first beam was observed in the experimental hall in December. Ten insertion devices were installed at first phase. The correction tables of COD and tune including non-linear magnetic field correction were prepared in January 2024. The golden orbit which was the target orbit of COD correction was decided at the stored beam current of 160 mA. The COD and tune corrections were performed every 30 seconds to achieve stable beam operation. The stored beam COD was monitored using 112 BPMs with several data acquisition methods such as turn-by-turn data with 859 kHz, fast data with 10 kHz and slow data with 10 Hz [10]. In case the COD monitored using the fast data with 10 kHz exceeds the orbital interlock threshold, the stored beam is aborted immediately within 500 µsec. Despite setting an interlock threshold of 0.14 mm at severest BPM, the stable beam operation was achieved. The current status of SR beam commissioning is shown in Table 2.

FIRST USER OPERATION

The first user time operation was started on April 9th 2024. The stored beam current was set to 160 mA with top-up beam injection. As shown in Fig. 7, the downtime due to the SR-RF interlock was only 1.9 hours out of a 296-hour user operation period. In the first user operation period, an operation availability, a ratio of the delivered user time to the scheduled one, was as high as 99.4%. The stored beam

Table 2: Designed and Measured Beam Parameters in SR Commissioning (160 mA)
*Assuming the designed value

Ring parameters	Designed value	Measurement
Horizontal emittance	1.14 nm rad	1.14 nm rad*
Vertical emittance	0.01 nm rad	0.02 nm rad
x-y coupling	1%	2.1%
Energy spread	0.084%	0.097%
Betatron tune(ν_x, ν_y)	(28.17,9.23)	(28.17,9.23)
Chromaticity(ξ_x, ξ_y)	(1.38,1.53)	(1.98,1.98)

profile was monitored using the XPC. The horizontal and vertical beam size were stable within 1 µm. In addition, the position variations were also stable within 5 µm.
The stored beam current will be increased to 250 mA in September 2024. The highly brilliant SX beam with a high coherent ratio has been started to be provided to users.

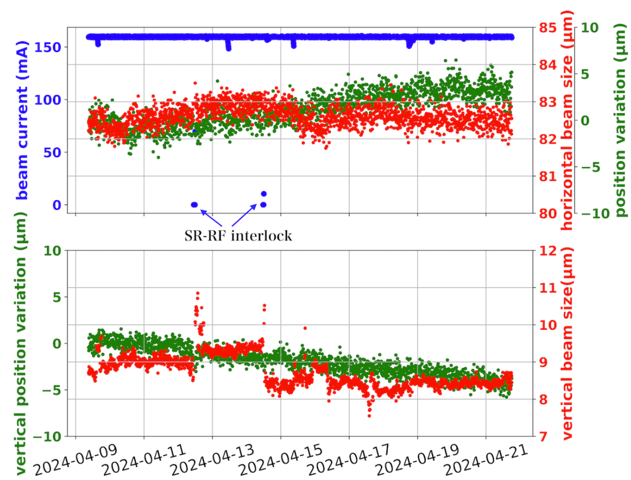

Figure 7: The horizontal (top) and vertical (bottom) stored beam stability in the first user operation period.

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REFERENCES

[1] N. Nishimori, T. Watanabe, and H. Tanaka, "Accelerator design report for 3-GeV next-generation synchrotron radiation facility", 2021.

[2] NanoTerasu web page, `https://nanoterasu.jp/`.

[3] T. Asaka *et al.*, "Low-emittance radio-frequency electron gun using a gridded thermionic cathode", *Phys. Rev. Accel. Beams*, vol. 23, p. 063401, 2020.

[4] T. Asaka, K. Ueshima, K. Kan, N. Nishimori, and T. Aoki, "Beam performance of injector system in NanoTerasu",, in

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Proc. 20th Annual Meeting of Particle Accelerator Society of Japan, Funabashi, Japan, 2023, p. THP49.

[5] H. Ego, *et al.*, “Compact HOM-damping structure of a beam-accelerating TM020 mode rf cavity”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1064, p. 169418, 2024.

[6] S. Takano *et al.*, “Renovation of Off-Axis Beam Injection Scheme for Next-Generation Photon Sources”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 2318–2321. doi:10.18429/JACoW-IPAC2019-WEPMP009

[7] S. Takano, M. Masaki, and H. Sumitomo, “Recent Progress in X-Ray Emittance Diagnostics at SPring-8”, in *Proc. IBIC’15*, Melbourne, Australia, Sep. 2015, pp. 283–287. doi:10.18429/JACoW-IBIC2015-TUCLA02

[8] K. Ueshima *et al.*, “Electron beam diagnostics system using 3-pole wiggler in NanoTerasu”, in *Proc. 20th Annual Meeting of Particle Accelerator Society of Japan*, Funabashi, Japan, 2023, p. THOA5.

[9] Z. Mart´ı, G. Benedetti, U. Iriso, and A. Franchi, “Fast beam-based alignment using ac excitations”, *Phys. Rev. Accel. Beams*, vol. 23, p. 012802, 2020.

[10] H. Maesaka *et al.*, “Design of the Beam Diagnostic System for the New 3 GeV Light Source in Japan”, in *Proc. IBIC’20*, Santos, Brazil, Sep. 2020, pp. 174–178. doi:10.18429/JACoW-IBIC2020-WEPP31