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STATUS OF LONGITUDINAL INSTABILITY SUPPRESSION AT NanoTerasu

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Abstract

NanoTerasu is a 3 GeV light source newly constructed in Sendai, Japan. The circumference is 349 m and the natural emittance is 1.14 nm rad, which is realized by a double-double-bend achromat lattice. The commissioning of the storage ring started in June 2023. The longitudinal instability was observed when the stored beam current reached 150 mA in August 2023. The temperature of SR RF cavity was adjusted to suppress the instability. The user operation was started on schedule in April 2024 with a stored beam current of 160 mA. The stored beam current was reached 200 mA without the beam instability in July 2024. The stored beam current at user operation period was limited to 200 mA due to the longitudinal instability. We tried to suppress the longitudinal instability using several methods. We developed the waveguide-overloaded kicker cavity and longitudinal bunch-by-bunch feedback (LBBF) system to suppress the instability. The LBBF system commissioning was carried out in July 2025. We achieved the 400 mA stable beam accumulation using LBBF system. The longitudinal instability suppression at NanoTerasu was reported.

INTRODUCTION

The NanoTerasu is a compact 3 GeV light source newly constructed in Sendai, Japan [1, 2]. The designed stored beam current is 400 mA. The commissioning of the storage ring started in June 2023 [3]. In August 2023, the longitudinal instability was observed when the stored beam current reached 150 mA. The user operation was started on schedule in April 2024 with a stored beam current of 160 mA. To suppress the longitudinal instability, the temperature of SR RF cavity was adjusted. However, the stored beam current was limited to 200 mA due to the longitudinal instability in 2024. To increase the stored beam current, we started to develop the waveguide-overloaded kicker cavity and LBBF system in January 2024. The kicker cavity was installed in the storage ring in May 2025. The commissioning of LBBF system was carried out in July 2025. The status of longitudinal instability suppression at NanoTerasu was reported.

LONGITUDINAL INSTABILITY

The accelerating cavity of the NanoTerasu storage ring adopts the world's first compact cavity that accelerates the stored beam in the TM020 mode [4]. The slot is placed at the magnetic field node of the axially symmetric TM020 mode. The ferrite-based RF absorbers are installed inside the slot. This structure is designed to attenuate higher order mode (HOM) components that can induce coupled bunch beam instabilities. During the commissioning of the storage ring, longitudinal instability was observed when the stored beam current exceeded 150 mA. As a result of investigating the accelerating cavity, this instability was attributed to the growth of a 1.9 GHz component of HOM. Figure 1 shows the spectrum of the 1.9 GHz HOM from the pickup of the accelerating cavity, as well as the frequency spectrum of the beam position monitor (BPM), during the occurrence of longitudinal beam instability. The sideband frequency components shifted by approximately 134 MHz from 508.76 MHz appeared in the BPM signal spectrum, indicating that the coupled-bunch mode number of the longitudinal instability was 156. Considering the temporal evolution of the spectrum intensity due to the longitudinal instability and the effect of the radiation damping, the growth rate of the 1.9 GHz HOM was estimated to be approximately 5.8 msec in 2023.

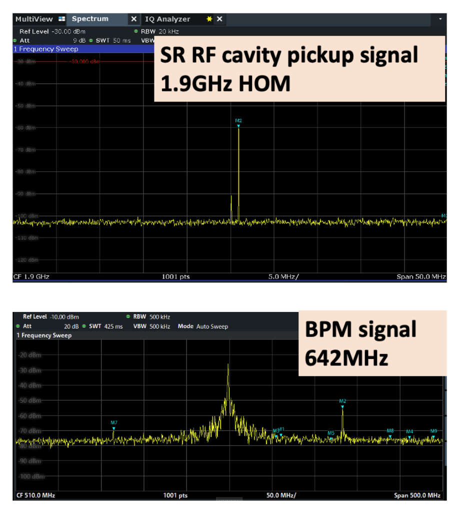

Figure 1: 1.9 GHz HOM signal from the pickup of the accelerating cavity (top) and spectrum of BPM signal (bottom).

At the energy dispersive section the X-ray pinhole camera (XPC) was installed to monitor the stored beam profile [5]. When the longitudinal beam instability increases the energy spread, the horizontal beam size also increases as shown in Fig. 2. The bunch phase is also monitored using the high speed digitizer ADQ7, which also measure the bunch current. The horizontal beam size and bunch phase are continuously monitored to detect the occurrence of the longitudinal instability.

To suppress the growth of the 1.9 GHz HOM, the cooling water condition of the accelerating cavity was adjusted, and

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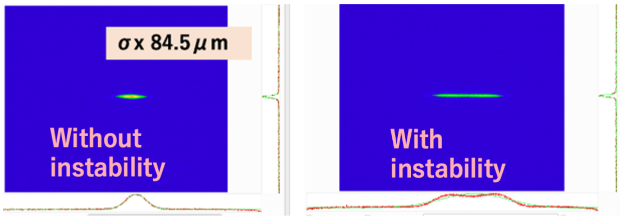

Figure 2: The stored beam profile without instability (left) and with instability (right).

user operation is currently being conducted at a stored beam current of 200 mA. Although parameters for stable long-term operation above 200 mA have not yet been identified, the instability growth rate is now longer than 6 msec. The growth rate is close to the radiation damping time and has significantly slowed compared to the growth rate in 2023.

LBBF SYSTEM

The waveguide-overloaded kicker cavity and longitudinal bunch-by-bunch feedback (LBBF) system were developed to suppress the instability. Figure 3 shows the layout of the LBBF system at NanoTerasu storage ring.

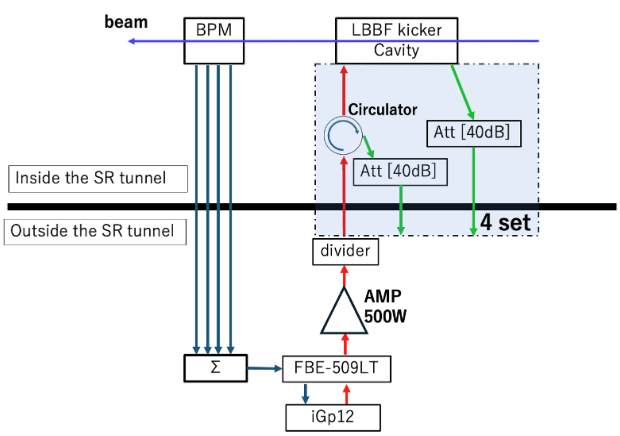

Figure 3: Layout of the LBBF system.

The longitudinal beam instability is detected by the BPM. The BPM sum signal is sent through a FBE-509LT and iGp12 developed by Dimtel Inc. The DAC output is sent to the back-end circuit of FBE-509LT. The back-end output signal is amplified by a 500 W solid-state amplifier developed by R&K. The output signal of 500 W AMP is fed into LBBF kicker cavity via a four-way splitter. The kicker cavity was designed based on the waveguide-overloaded kicker cavity, which has been widely used in longitudinal BBF systems [6–10]. The kicker cavity was designed with a driving frequency of 1.65 GHz, which corresponds to $(3 + \frac{1}{4})f_{RF}$. The f_{RF} is 508.76 MHz. The 1 dB bandwidth was set to more than 255 MHz. In order to apply accurate kicks to each bunch, the loaded quality factor (Q_L) was designed to be less than 10. A compact kicker cavity was designed with four input and four output ports. The total length between both ends of the back cavity is 133 mm as shown in Fig. 4.

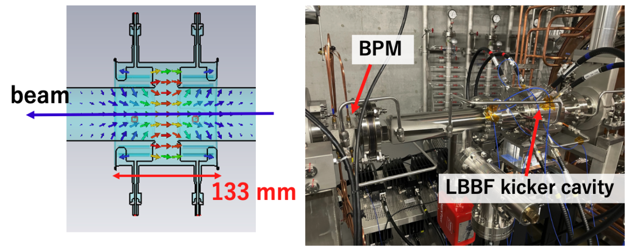

Figure 4: The RF simulation of the LBBF kicker cavity (left). The installed LBBF kicker cavity and BPM to monitor the longitudinal instability (right).

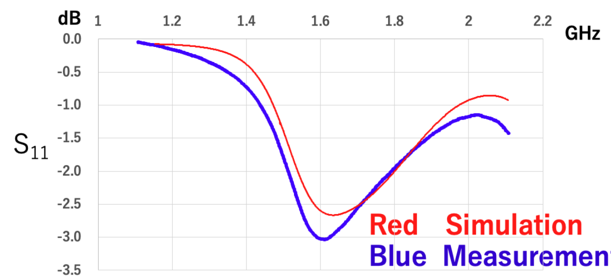

Figure 5: Comparison of measured and simulated S11 distribution.

The S-parameters measured after welding and assembly of the LBBF kicker cavity were close to designed values as shown in Fig. 5 and Table 1. The Q_L value estimated from the S11 parameter was approximately 3.0. After fabrication, the shunt impedance was estimated to be approximately 700 Ω by the bead ball perturbation measurement.

Table 1: RF Characteristics of Developed LBBF Kicker Cavity

	Designed value	**Measured value**
Center frequency	1652GHz	1.609 GHz
1 dB Bandwidth	317 MHz	271 MHz
Q_L	3.4	3.0

LBBF Commissioning

The developed LBBF kicker was installed in the storage ring in May 2025. The commissioning of the LBBF system was carried out in July 2025. The damping time of LBBF system was estimated by the grow damp method as shown in Fig. 6. The single bunch at 1 mA was excited at the synchrotron frequency of 5.19 kHz. Without BBF, the damping time was approximately 7 msec corresponding to radiation damping time. By increasing the BBF gain, the damping time was shortened to approximately 2.5 msec. Considering the radiation damping time, the effective LBBF damping time was estimated to be 3.9 msec in case the BBF gain is 4. The damping time of developed LBBF system is shorter than growth rate of the 1.9 GHz instability observed in 2023. We

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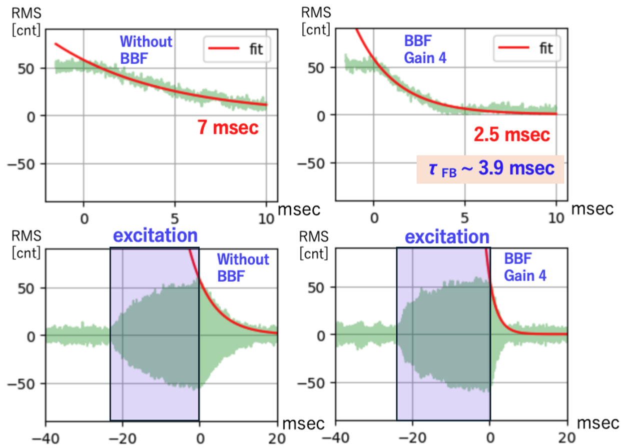

Figure 6: The result of grow damp measurement without BBF (left) and with BBF (right). The top tow figures show enlarged views of the beam damping.

confirmed that the LBBF system provided sufficient feedback performance.

The feedback phase of LBBF system was adjusted, and a beam accumulation test was carried out up to 400 mA. The number of taps for instability detection was set to 32. To efficiently detect the instabilities caused by synchrotron oscillation, the down sampling factor was set to 5. As a result, the LBBF system successfully suppressed the instability caused by the 1.9 GHz HOM. We achieved the stable beam accumulation up to 400 mA as shown in Fig. 7.

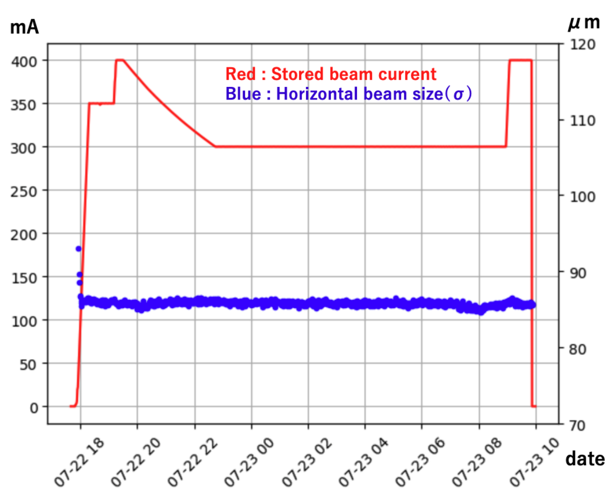

Figure 7: The stored beam current and horizontal beam size distribution with the suppression of longitudinal instability.

By applying the LBBF system, the phase spread of each bunch was significantly improved. Even at a stored beam current of 400 mA, the phase spread of all 550 bunches was suppressed to 0.5 psec (std) as shown in Fig. 8. Still it was difficult to keep 400 mA due to the heat problem at kicker magnet. We plant to increase cooling unit of kicker magnet in this summer.

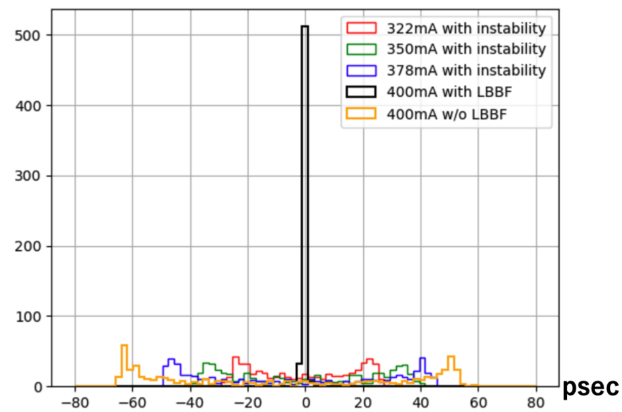

Figure 8: The bunch phase distribution of all 550 bunches. The longitudinal instability leads to a large bunch phase spread as the stored beam current increases.

SUMMARY

We successfully developed the LBBF system to suppress the longitudinal instability at NanoTerasu storage ring. The 400 mA stable beam accumulation using LBBF system was achieved.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Accelerator Design Report for 3-GeV Next-Generation Synchrotron Radiation Facility, Sep.2020, `https://www.qst.go.jp/uploaded/attachment/18596.pdf`

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

[3] S. Obara *et al.*, "Commissioning of a compact multibend achromat lattice NanoTerasu: A new 3 GeV synchrotron radiation facility,"*Phys. Rev. Accel. Beams*, vol. 28, no. 2, Feb. 2025. `doi:10.1103/physrevaccelbeams.28.020701`

[4] H. Ego *et al.*, "Compact HOM-damping structure of a beam-accelerating TM020 mode rf cavity,"*Nucl. Instrum. Methods Phys. Res. A*, vol. 1064, p. 169418, Jul. 2024. `doi:10.1016/j.nima.2024.169418`

[5] K. Ueshima *et al.*, "Commissioning of the Beam Diagnostic System for NanoTerasu: a new 3 GeV Light Source in Japan", in *Proc. IBIC'24*, Beijing, China, Sep. 2024, pp. 5–10. `doi:10.18429/JACoW-IBIC2024-TUBI1`

[6] R. Boni *et al.*, "A Waveguide Overloaded Cavity as Longitudinal Kicker for the DAΦNE Bunch-by-bunch Feedback System", *Particle Accelerator*, vol.52. pp.95–113, 1996.

[7] Y. Kim *et al.*, "Longitudinal feedback system kicker for the PLS storage ring,"*IEEE Trans. Nucl. Sci.*, vol. 47, no. 2, pp. 452–467, Apr. 2000. `doi:10.1109/23.846279`

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ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPCO08

[8] W. Z. Wu *et al.*,"Development of a bunch-by-bunch longitudinal feedback system with a wide dynamic range for the HIGS facility,"*Nucl. Instrum. Methods Phys. Res. A*, vol. 632, no. 1, pp. 32–42, Mar. 2011. `doi:10.1016/j.nima.2010.12.077`

[9] A. F. D. Morgan and G. Rehm, "Initial Work on the Design of a Longitudinal Bunch-by-Bunch Feedback Kicker at Diamond", in *Proc. IBIC'15*, Melbourne, Australia, Sep. 2015, pp. 197–201. `doi:10.18429/JACoW-IBIC2015-MOPB064`

[10] A. F. D. Morgan and G. Rehm, "Design for the Diamond Longitudinal Bunch-by-Bunch Feedback Cavity", in *Proc. IBIC'16*, Barcelona, Spain, Sep. 2016, pp. 340–343. `doi:10.18429/JACoW-IBIC2016-TUPG12`

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