ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG28

STATUS OF THE TRANSVERSE BUNCH-BY-BUNCH FEEDBACK SYSTEM AT APS-U STORAGE RING*

W. Cheng†, A. Brill, X. Sun
Argonne National Laboratory, Lemont, IL 60439, USA

Abstract

A transverse bunch-by-bunch (BxB) feedback system has been designed, fabricated, installed, and tested with the beam at the Advanced Photon Source Upgrade (APS-U) storage ring. The transverse feedback system (TFB) suppresses coupled and single-bunch instabilities. It adapts a stripline kicker design with the same profile as the APS-U injection/extraction kickers. The system uses digital controllers, which provide powerful diagnostics in addition to its primary functionality for feedback control. This paper presents the status of the TFB system, including preliminary beam commissioning results.

INTRODUCTION

Ultra-low emittance storage rings like APS-U have small gap vacuum chambers and unavoidable discontinuity structures, which introduce geometrical impedance and resistive wall impedance. Additionally, residual gases and ionization by the electron beam will likely cause ion instabilities. An active transverse feedback system has been designed and constructed to cure the coupled bunch instabilities. The system should also be able to suppress the single-bunch instabilities.

Table 1: Major parameters for APS-U TFB System

Parameter	Value	Unit	Notes
E	6	GeV	Energy
I	200	mA	Current
f_{rf}	352.055	MHz	RF frequency
h	1296	-	Harmonic #
f_{rev}	271.65	kHz	Rev. freq.
T_{rev}	3.68	μs	Rev. period
Pattern	48 or 324	bunches	Fill patterns
Q_x/Q_y	95.10/36.10	-	Tune
f_x/f_y	27.2/27.2	kHz	Betatron frequency
τ_x /τ_y	6.85/15.40	ms	Rad. damping time
τ_{fb}	<500	μs	FB damping time
R_{Shunt}	>10	kOhm	Stripline shunt imp.
Power	2*500	W	Power per plane
Stripline length	240	mm	<=λ_{rf}/2, to kick the individual bucket

The TFB system has been designed to have a damping time of 500 μs or less at 200mA full current. Table 1 summarizes the major parameters of the APSU storage ring and the TFB system. Active feedback systems are widely used in modern storage rings and generally meet the design performance. Its performance shall be however to be best optimized with other knobs (like chromaticity or octupole magnets). APSU will have the same betatron tunes in X/Y planes, which may introduce extra complications. The design is to have two identical feedback loops, one for each plane and with separate pickups and kickers. As listed in Table 2, BP3 and AP2 BPMs at large β_x/β_y locations are selected. An additional BPM pickup is reserved as the AP2 BPM has a photon extraction slot and antechamber structure; the spare BPM S39AP0 can be used in case the AP2 BPM has trapped higher order modes (HOM), which may fall in the detection frequency range. For the stripline kickers, due to space limitation, both kickers are installed in the S38 straight section, where the β-function is not ideal. The table lists the β-function values from the straight center for the kickers. The actual installation of the kickers is toward the downstream end of the straight section, so β-functions are slightly larger (roughly 6m/5m for x/y, respectively).

Table 2: TFB BPM pickup and kicker locations

Components	β_x/β_y [m]	η_x [m]	Notes
S38B:P3	**12.48**/7.24	0.088	Large β_x, suitable for X feedback
S39A:P2	5.32/**17.40**	0.056	Large β_y, suitable for Y feedback
S39A:P0	6.66/5.57	0.0004	Spare BPM
Kickers	5.20/2.39	0.0004	β_x/β_x at ID center

Feedback systems are typically composed of three parts: 1) The RF front end to detect the transverse position error signal (or phase/energy information for the longitudinal plane). 2) A high-speed digitizer to sample and process the analog signals, which includes feedback gain control, phase adjustment, etc. 3) Corrector module which includes high power amplifier and kickers.

The digital feedback controller removes the DC offsets and revolution harmonics by digital filtering; only interested betatron oscillations are selected for the process. Digital delay and phase adjustment can be easily implemented to apply the correction signals when the beam circulates back in the following turns. In addition to its primary function of suppressing instability, the digital controller can also be a powerful diagnostic tool. Benefiting from the large memory buffer, the controller can acquire/analyze bunch-to-bunch position/phase information to reveal the unstable modes. Betatron tunes can also be measured for individual bunches. The system can also resonantly excite unwanted bunches and knock them out. Commercially available controllers [1] have been selected, and the controllers have been used in the APS storage ring.

500W amplifiers from Amplifier Research [2] have been used at the APS storage ring. The APSU TFB adopted the

*Work supported by DOE contract No: DE-AC02-06CH11357
#†wcheng@anl.gov

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG28

same amplifiers, so the original amplifiers can be reused. The amplifiers have a bandwidth of 10kHz—250MHz. New stripline kickers are needed, as described in the next section.

STRIPLINE KICKERS

Although the kick strengths are more than required, it has been decided to adopt a similar stripline kicker design as the injection kickers (IK) [3] and decoherence kickers (DK). The electrode face-to-face distance was 9.9mm, and the TFB kickers' electrode length was 240mm, which is the same length as the DK and one-third the length of the IKs. While the IK and DK kickers have custom-designed feedthroughs that can tolerate 30kV of pulse voltages, the TFB kickers do not have such high peak voltage requirements. And because of that, commercially available Kyocera feedthroughs are selected for the TFB kickers. The feedthrough has a better impedance match and, hence, has better high-frequency responses.

The kicker profile was first optimized in 2D to match the characteristic impedance. There are two modes for a two-electrode stripline: differential mode or common mode (sometimes called odd/even modes). In the differential mode, the two electrodes have different polarity (+/-) voltages applied, while the common mode has the same polarity (+/+). As the major functionality of the TFB stripline is to be used as a kicker, the differential mode was optimized to match 50-Ohm. The common mode impedance was simulated to be around 63-Ohm.

With the optimized 2D profile, the 3D models of the stripline kickers were further optimized with CST Studio [4]. Figure 1 shows a model of the kicker, including feedthroughs. The kicker body has a tapered structure on both ends, which helps to minimize the beam impedance. The feedthrough ceramic gaps and other details were included in the model.

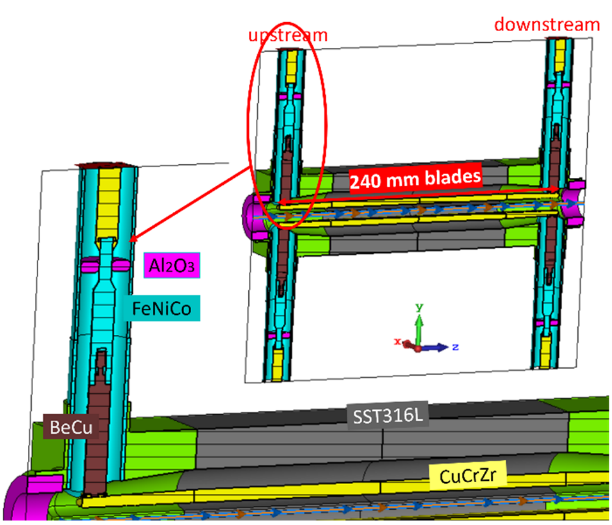

Figure 1: CST model of the TFB stripline kicker

The TFB kickers, together with IKs and DKs, were fabricated/assembled at Brookhaven National Laboratory (BNL). Figure 2 shows one assembled TFB kicker being tested in the lab using a Teledyne Lecroy WavePulser TDR. Similarly, frequency domain testing was carried out using a 4-port VNA.

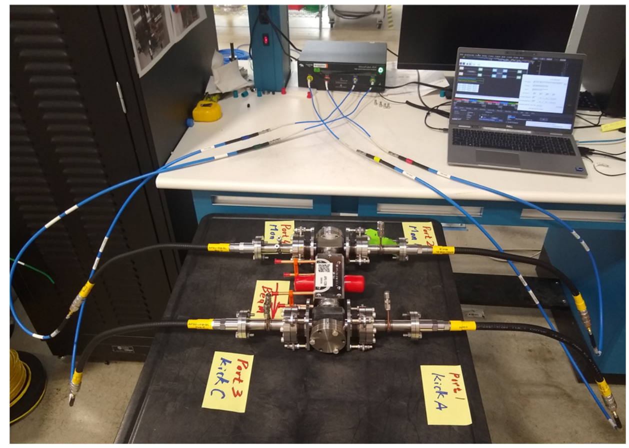

Figure 2: Assembled TFB stripline kicker and test setup in the lab.

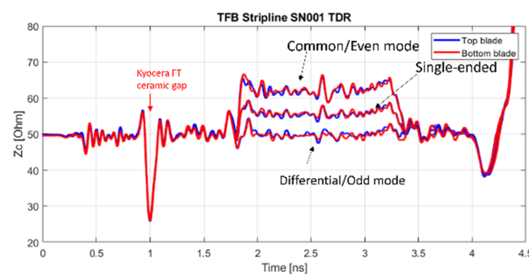

Figure 3: TDR results for different modes for one of the TFB stripline kickers.

INSTALLATION AND PRE-BEAM TESTING

Each assembled stripline kicker has been tested in the lab, like the setup in Figure 2. The TDR results for one of the kickers are shown in Figure 3. The measured common/differential mode impedances agree well with the simulated results. Frequency domain response shows a good transmission up to 1.5GHz.

Two stripline kickers have been installed in the tunnel, as shown in Figure 4. The X and Y kickers are identical but rotated by 90 degrees. Six thermocouple sensors are mounted per kicker to monitor temperatures at the feedthroughs and kicker body. Cooling water channels were also added as a precaution. ½" Heliax cables are used to connect the kickers to RF amplifiers or attenuators on the mezzanine. The cable lengths are around 21 m, and each pair is phase matched.

The TFB electronics, RF amplifiers, and loads are all installed on the mezzanine racks. After installation, the feedback control loop has been tested before beam commissioning. Figure 5 shows the S21 of the horizontal plane loop, including the amplifier, long-haul cables, and 30dB attenuators. The measurement used the VNA mixed mode; hence, the differential mode and common mode S21

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG28

can be measured. The amplifier gain shall be around 60dB, considering the 30dB attenuators. The bandwidth of the amplifiers is sufficiently large. There is little difference for the common mode at such low frequency, except the common mode trace has small ripples. That is likely related to the stripline kickers' higher characteristic common mode impedance, as shown in Figure 3.

Figure 4: TFB kickers as installed in the APSU tunnel.

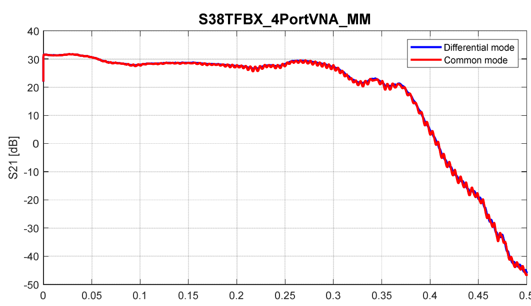

Figure 5: Measured S21 of amplifiers, cables, and attenuators installed for the horizontal plane TFB feedback loop.

FIRST BEAM EXPERIENCE

APSU beam commissioning started in April 2024. So far, several milliamperes of stored beam have been achieved, and no coupled bunch instabilities have been observed at such low current. Parasitically, the feedback controllers have been tuned with proper timing, gains, and digital filtering; the feedback loop can be enabled when necessary.

The TFB system, though, has been used to measure the betatron frequencies by exciting the beam slightly with a chirp signal. Figure 6 shows the single bunch spectrum with excitation in the vertical plane. The frequency at ~40kHz is the vertical betatron frequency (corresponding to a fractional tune of 0.147). The noise at around 15.7kHz has been observed from the spectrum, but the source is unknown. 360Hz, 720Hz, and similar 60Hz harmonics are also seen; those are related to the RF noises. The synchrotron tune hump is around 550Hz. It is worth pointing out that the horizontal tune hump is wider, probably due to larger chromaticity (and wider tune spread). In this case, the excitation around the betatron frequencies may not be the best method. Other potential methods can be explored; for example, the betatron frequencies can be determined from the notches [5] when feedback is switched on. Alternatively, they can be determined from the phase response (instead of amplitude) of the transfer function.

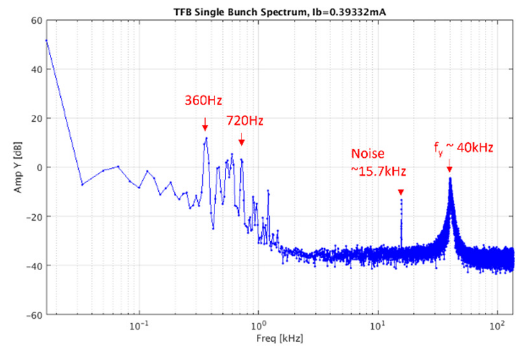

Figure 6: Single bunch spectrum with sweeping excitation signal turned on.

SUMMARY AND ACKNOWLEDGMENTS

The TFB system at the APSU storage ring has been fully installed, tested, and preliminarily commissioned with beam. Betatron tunes can be measured even with a relatively low storage current. As the beam current increases, we expect the system to be critical to suppressing the coupled bunch and single bunch instabilities. We would like to report the progress of the system in the future.

We thank the BNL team (Belkacem Bacha, Charles Hetzel, Bernie Kosciuk, Danny Padrazo, Michael Seegitz) for helping fabricate and test the stripline kickers and Uli Wienands and Jie Liu for various discussions. We also greatly appreciate support and encouragement from APSU/APS managers.

The work is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

REFERENCES

[1] `https://www.dimtel.com/`

[2] `https://arworld.us/rf-amplifiers/`

[3] X. Sun, and C. Yao, "Simulation Studies of a Prototype Stripline Kicker for the APS-MBA Upgrade", *in Proc. NAPAC'16*, Chicago, IL, USA, Oct. 2016, pp. 928-930. `doi:10.18429/JACoW-NAPAC2016-WEPOB16`

[4] `https://www.3ds.com/products/simulia/cst-studio-suite`

[5] W. X. Cheng, B. Bacha, Y. Li, and D. Teytelman, "Developments of Bunch by Bunch Feedback System at NSLS-II Storage Ring", *in Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 1833-1836. `doi:10.18429/JACoW-IPAC2018-WEPAF011`