ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB134

EXPERIMENTAL STUDIES OF THE IN-VACUUM-CRYOGENIC UNDULATOR EFFECT ON BEAM INSTABILITIES AT BESSY II

M. Huck*, J. Bahrdt, A. Meseck, G. Rehm, M. Ries, A. Schälicke
Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany

Abstract

A new in-vacuum cryogenic permanent magnet undulator (CPMU17) has been installed in summer 2018 in the BESSY II storage ring at HZB. Such a small gap in-vacuum undulator device increases the impedance of the storage ring and can contribute to the instabilities that adversely affect the beam quality and the device itself. To identify and explore the effects of CPMU17 on the instabilities at BESSY II, grow-damp and drive-damp experiments have been conducted using the installed bunch-by-bunch feedback system. In this paper, the first results of the mode and gap analysis of these studies with a brief overview of other impedance studies will be presented.

INTRODUCTION

The first radiation from the cryogenic permanent magnet undulator (CPMU17) has been observed in December 2018 at the BESSY II storage ring at HZB [1], and since then this device has served as a light source for beamline commissioning. Recently, first user experiments are started. Beam-based measurement using orbit-bump and tune-shift technique, and simulation tools were used to estimate the impedance of CPMU17 [2, 3].

During regular BESSY II operation, it was observed, that at small gaps of CPMU17, the injection efficiency of the machine decreased. This effect was however was relieved to good extent by improving the machine optics, and the effect of ID on optics seems to be of more relevance in this matter. Furthermore, the temperature of ID taper and magnet girder increases at small gaps, especially at low powers of the 3^{rd} harmonic "Landau" cavities. These four cavities were originally installed to increase the beam life time. Now, they are also required to decrease the impedance heating effects of the device by expanding the bunch length by ~ 30%. Therefore, a study of CPMU17 effect on the beam stability was required, as done before at SPEAR3 in SLAC [4–6], Australian light source [7, 8] and Diamond light source [9, 10]. In SPEAR3 and Australian light sources, unstable modes were detected directly correlated to the IVU gaps. And especial measures were taken to mitigate them e.g by using ferrite dampers.

MEASUREMENTS

In this study, the undulator gap was varied with a speed of 0.01-0.05 mm/s (10-50 µm steps), from 22 mm (opened) to 6 mm (closed), and beam oscillations were scanned for several beam current and landau-cavities power. Two feedback systems were used for this purpose: First, a transverse multi-bunch feedback which was originally developed and installed at the Diamond light source (DLS-TMBF) [11–13] and was later integrated at the ALBA storage ring [14], and recently at the BESSY II. This system has the ability to record complex amplitudes of the beam oscillation, yielding the amplitude and frequency for each mode. And the second was a bunch by bunch (BxB) feedback systems from Dimtel, Inc. [15] based on iGp12 processor. Both systems use field-programmable gate arrays (FPGA), an integrated circuit for complex filter functions.

Grow-damp and Drive-damp Studies for CPMU17

In our ***first attempt***, grow-damp studies were performed using iGp12 in all three planes. In this technique, the BxB feedback loop is opened for a short time, and the growth of the bunch-oscillation amplitude are observed, then the loop is closed and the oscillations are damped. Example results at a gap of 6 mm are shown in Fig. 1. The fill pattern was a uniform bunch train with total current of ~ 280 mA in 380 buckets; 20 buckets was left empty for ion-clearing. The chromaticity was at its typical operational values of $\xi_x \sim 2.2$, $\xi_y \sim 2.8$.

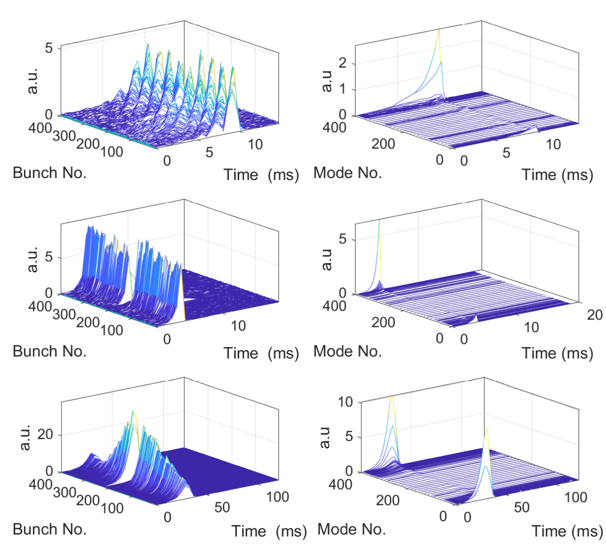

Figure 1: Bunch oscillation envelope (left) and evolution of modes (right) in y, x and z planes (top to bottom).

A strong amplitude of mode number 390 and 399 can be seen in vertical (y) plane in all gaps, related to the ion trapping and resistive impedance, respectively. In the longitudinal (z) plane, the dominant modes are 0 and 399 and in horizontal (x) plane the mode 399. Small peaks at modes 0 and 1 in all planes (stronger in z plane) are side bands of the resistive mode 399. No effect of ID gap variation on modes growth-rates was found in ***all 3 planes***.

* maryam.huck@helmholtz-berlin.de

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB134

In the ***second attempt***, we used drive-damp technique instead of grow-damp, with a current of 11 mA, i.e. well below the instability threshold. In the grow-damp method, the modes grow from noise; hence the most unstable modes have the biggest chance to grow and dominate the others. But, by exciting the modes individually, each mode has the chance to grow, regardless of the stability degree. Figure 2 shows iGp12 tune tracking of mode 1 for bunches 1 and 212, with different bunch current at gap 22 mm. They have different open-loop tunes due to the current-dependent tune shift of ~ 85 Hz. In range of 5-15 ms, there are clear slope and open-loop frequency differences. In 0-5 ms range (while excitation is active), tune variation is smaller. As tune varies around center frequency ν_y = 331.5 kHz (Q_y = 0.27), amplitude of the response goes up and down, reflecting the tune variation. The damping time is around 5 ms and the modulation period is 3 ms. So, as the beam oscillates it responds to the drive as well as to tune jitter. Hence, the determination of damping times, which are also influenced, becomes difficult, particularly the stable modes and the modes with damping time larger than jitter time. This jitter is probably caused mainly by the ripple at 300 Hz of quadrupole power supplies.

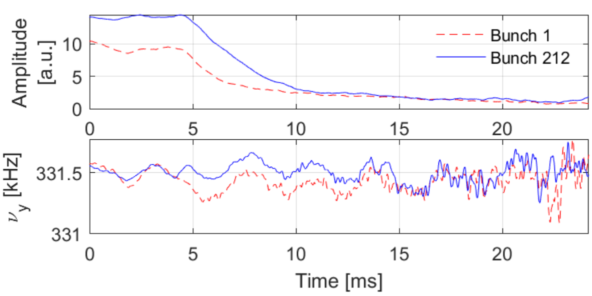

Figure 2: Tune tracking for two bunches for mode 1.

In the ***third attempt***, the excitation time was reduced to 0.4 ms, much smaller than the tune jitter time. Furthermore, a fill pattern without ion clearing gap was used, and the bunch currents were made equal to about 5% (rms). The vertical chromaticity was reduced to ξ_y = 0 (for stronger mode evoking). We also restricted our measurements to the vertical plane, since this is the most relevant plane regarding the ID effect. The beam was excited mode-by-mode using DLS-TMBF system for 500 turns (0.4 ms), and then the passive mode-growth (open feedback loop) was observed for 2000 turns (1.6 ms). Finally, the oscillation was damped actively (closed loop) for 5000 turns (4 ms), and this process was repeated for all 400 modes. An example plot of growth rate vs. ID gap and mode numbers (beam current 187 mA) is shown in Fig. 3 (top), and for five measurements with different beam currents and Landau power (bottom). The damping times are fitted over 10-20 samples, each sample resembling 100 turns. Three different regions can be distinguished by growth rate in these plots: damping (negative growth rate), nearly stable (growth rate near zero) and growing (positive growth rate). Figure 3 bottom shows, that with

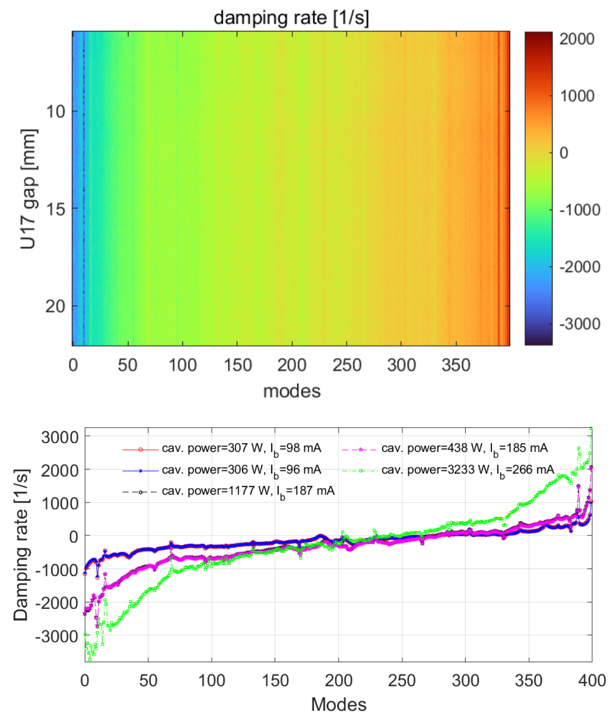

Figure 3: Damp rates vs. ID gap (top) and for different beam currents and Landau power, averaged over all gaps (bottom).

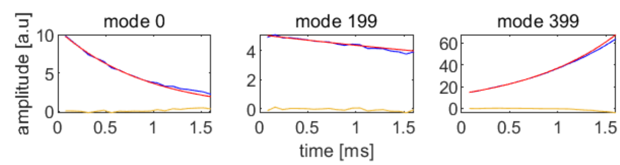

Figure 4: Three example fits of the damping rates, with blue curve the measured data, red curve the exponential fit, and yellow one their difference.

increasing the current, the magnitude of the growth rates of positive and negative modes increase. Figure 4 shows 3 example data-fits at each 3 damping regions. In most data, there is a slight deviation from exponential, at the highest modes and currents. In this case, the beam current was here 96 mA and ID gap 6 mm. Figure 5 top shows the shift of the vertical oscillation frequency ($\Delta\nu_y$) of the excited beam with respect to the vertical betatron frequency of ν_y = 900.8 kHz (Q_y = 0.72), at current of 187 mA. Averaged over all gaps (for different currents) in Fig. 5 bottom, regular ripples can be clearly seen in $\Delta\nu_y$, indicating regular changes in betatron frequency. By subtracting the mean of $\Delta\nu_y$ and averaging over all modes, a gap-dependent pattern can be seen (Fig. 6 top), that clearly indicates the non-perfect tune-correction tables of the ID. The same pattern can be seen in the damp rates in Fig. 6 middle, especially at high currents, but the changes are very small, in the range of ±30 [1/s]. Figure 6 bottom shows the damp rates for mode 399. The growth rate increases with beam current. Changing the Landau power at current ~ 186 mA did not change the growth rates significantly. And clearly there is no gap-dependency of damp rates.

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB134

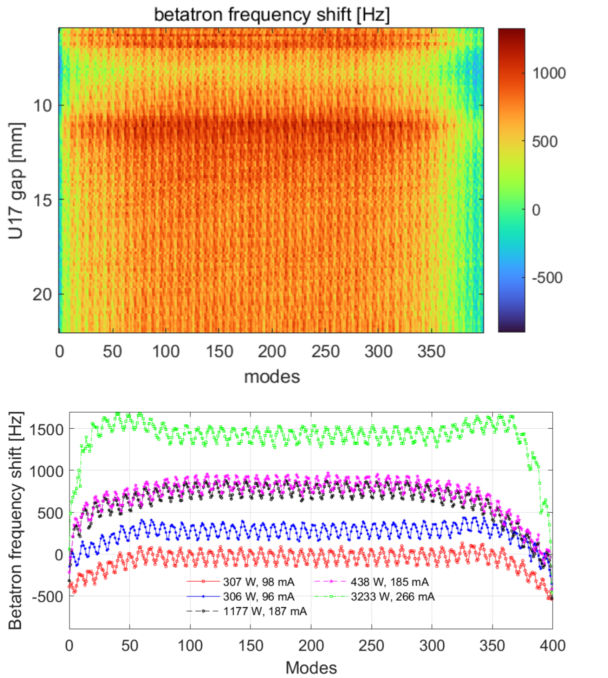

Figure 5: Frequency shifts at current of 187 mA (top) over gap (bottom).

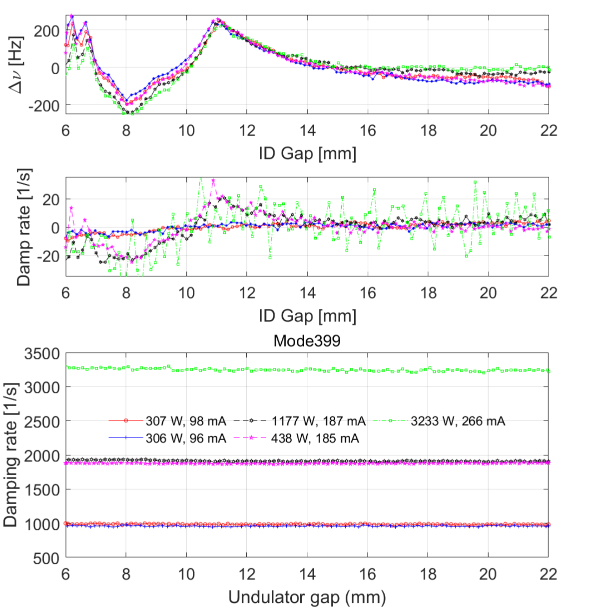

Figure 6: $\Delta\nu_y$ (top) vs. gap, damp rates averaged over modes vs. gap (middle), damp rates vs. ID gaps (bottom) for one mode. Legends are the same.

Another aspect of this study was investigating the ***variation of growth rates and frequencies with beam current*** (Fig. 7) with the aim of estimating the impedance at each mode [16–19]. The analysis of this data is still ongoing and needs more data collection and studies.

Drive-damp Studies for Scraper

As comparison to the IVU, and complementary measurement with the new DLS-TMBF, we studied the effect of a

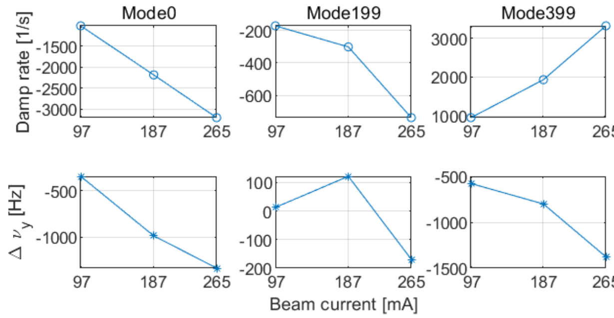

Figure 7: Damp rates and $\Delta\nu_y$ vs. beam current.

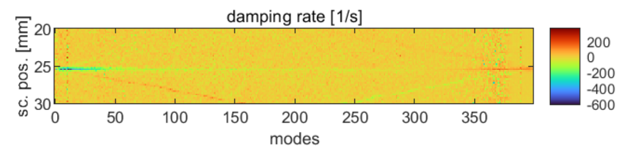

Figure 8: Damp rates vs. scraper position (sc. pos.).

scraper, that is used to reduce the beam current at BESSY II. The vertical position of the scraper was changed, and grow-damp times were extracted from drive-damp experiments (Fig. 8). Clear modifications to the modes at a scraper position of 25.4 mm can be seen, together with 4 diagonal features above and below. The picture indicates, that a resonance condition is observed, which depends on the position of the scraper. The resonance seems to cross a harmonic of fundamental ($n \times 500$ MHz) at a position of 25.4 mm. In this image, the mean value of the grow rates (over the gaps) has been subtracted from data, to see these features better; otherwise the background features and traces (e.g. the vertical lines) was the same as those in Fig. 3.

CONCLUSION AND OUTLOOK

After performing extensive grow-damp studies (in three planes) and drive-damp studies (in vertical plane), using two different feedback systems, the main conclusion is, that no changes to transverse coupled bunch damping could be observed for variation of the CPMU17 gap, unlike the instabilities found in other cases in [4–10] using the same technique. Also, no harmful modes were found, that could be linked to a heating event in vacuum components of the transition region of the CPMU17 (2019), confirming that an upstream-dipole radiation was the main responsible for that [20]. However, the temperature of CPMU17 varies by gap changes, clearly due to the wakefields, but this only affects the vacuum pressure, which is an issue for gas lifetime and Bremsstrahlung and is a source of gas-loss-rate (when ID is closed). Further related studies could be: the current-dependent mode-growth with better accuracy and more data to deduce the impedance spectra, understanding frequency and amplitude modulation, comparison of iGp12 and DLS system, installation of RF-antennas in IVU chamber and using a spectrum analyzer as a complementary bench measurement to beam based measurements.

ACKNOWLEDGMENTS

The authors would like to acknowledge with much appreciation D. Teytelman (Dimtel, Inc.) for his great support.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB134

REFERENCES

[1] J. Bahrdt *et al.*, "Characterization and Implementation of the Cryogenic Permanent Magnet Undulator CPMU17 at Bessy II", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 1415–1418. doi:10.18429/JACoW-IPAC2019-TUPGW014.

[2] M. Huck, J. Bahrdt, H. Huck, A. Meseck, and M. Ries, "Transverse Broad-band Impedance Studies of the New In-vacuum Cryogenic Undulator at BESSY II Storage Ring", in *Proc. International Beam Instrumentation Conference 2020 (IBIC'20)*, Santos, Brazil, Sep. 2020, pp. 263–267. doi:10.18429/JACoW-IBIC2020-THPP26.

[3] M. Huck, J. Bahrdt, and A. Meseck, "First Numerical Wakefield Studies of New In-Vacuum Cryogenic and APPLE II Undulators for BESSY II", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2021, paper WEPAB133.

[4] K. Tian, J. J. Sebek, and J. L. Vargas, "Investigation of Transverse Beam Instability Induced by an In-vacuum Undulator at SPEAR3", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 31–34. doi:10.18429/JACoW-IBIC2016-MOPG03

[5] K. Tian, J. J. Sebek, A. D. Ringwall, and Z. Li, "Damping trapped modes in an in-vacuum undulator at a synchrotron radiation light source", *Phys. Rev. Accel. Beams*, vol. 22, no. 5, May 2019. doi:10.1103/physrevaccelbeams.22.050702

[6] K. Tian, J. Sebek, J. L. Vargas, "Investigation of Transverse Beam Instability Induced by an In-vacuum Undulator at SPEAR3", SLAC National Accelerator Laboratory, Menlo Park, USA, Rep. SLAC-PUB-16824, Mar. 2016.

[7] R. T. Dowd, M. P. Atkinson, M. J. Boland, G. LeBlanc, Y. E. Tan, and D. Teytelman, "Investigation of Trapped Resonant Modes in Insertion Devices at the Australian Synchrotron", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 1710–1713. doi:10.18429/JACoW-IPAC2016-TUPOR023

[8] R. T. Dowd, W. J. Chi, and D. Pelz, "Investigation of Options for Damping Trapped IVU Resonances", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 1296–1299. doi:10.18429/JACoW-IPAC2018-TUPMF021

[9] R. Bartolini, R. T. Fielder, G. Rehm, and V. V. Smaluk, "Analysis of Multi-bunch Instabilities at the Diamond Storage Ring", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 1685–1687. doi:10.18429/JACoW-IPAC2016-TUPOR013

[10] R. Bartolini, R. T. Fielder, E. Koukovini-Platia, and G. Rehm, "Multi-Bunch Instabilities Measurement and Analysis at the Diamond Light Source", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 4485–4488. doi:10.18429/JACoW-IPAC2017-THPVA028

[11] A. F. D. Morgan, G. Rehm, and I. Uzun, "First Tests of the Transverse Multibunch Feedback at Diamond", in *Proc. 8th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC'07)*, Venice, Italy, May 2007, paper WEPB28, pp. 295–297.

[12] G. Rehm, M. G. Abbott, and A. F. D. Morgan, "New Features and Measurements using the Upgraded Transverse Multibunch Feedback at Diamond", in *Proc. 3rd Int. Beam Instrumentation Conf. (IBIC'14)*, Monterey, CA, USA, Sep. 2014, paper WEPD24, pp. 696–699.

[13] A. F. D. Morgan, M. G. Abbott, and G. Rehm, "First Experiences with the Longitudinal Feedback System at Diamond Light Source", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 1992–1995. doi:10.18429/JACoW-IPAC2017-TUPIK114

[14] A. Olmos *et al.*, "Integration of the Diamond Transverse Multibunch Feedback System at ALBA", in *Proc. 4th Int. Beam Instrumentation Conf. (IBIC'15)*, Melbourne, Australia, Sep. 2015, pp. 414–417. doi:10.18429/JACoW-IBIC2015-TUPB046

[15] "DIMTEL INC.", https://www.dimtel.com/.

[16] D. Teytelman, J. Fox, S. Prabhakar, and J. M. Byrd, "Characterization of longitudinal impedances in storage rings via multibunch effects", *Phys. Rev. ST Accel. Beams*, vol. 4, no. 11, Nov. 2001. doi:10.1103/PhysRevSTAB.4.112801

[17] S. Khan, *Collective Phenomena in Synchrotron Radiation Sources*. Berlin, Heidelberg, Germany: Springer, 2006.

[18] A. W. Chao, *Physics of collective beam instabilities in high-energy accelerators*. New York, NY, USA: Wiley, 1993.

[19] D. Teytelman, "Architectures and algorithms for control and diagnostics of coupled bunch instabilities in circular accelerators", Ph.D. thesis, Dept. of Electrical Engineering, Stanford University, Stanford, USA, 2003.

[20] J. Bahrdt *et al.*, "Internal report on heating event in vacuum components of the transition region of the CPMU17 (2020)", unpublished.