ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC58

NARROWBAND IMPEDANCE STUDIES IN THE HEPS STORAGE RING

N. Wang†, J.T. Li[1], S. K. Tian, S. Yue, X. Y. Liu
IHEP, CAS, Beijing 100049, China
[1]also at University of Chinese Academy of Sciences, 100049, Beijing, China

Abstract

The High Energy Photon Source (HEPS) is a fourth-generation synchrotron radiation facility with design beam emittance of less than 60 pm. Impedance modelling is an important subject due to the adopted small beam pipe as well as the tight requirements from beam collective effects. Narrowband impedances can be generated by the discontinuity of the vacuum chamber or the finite conductivity of the beam pipe. The coupled bunch instabilities caused by the narrowband impedances could restrict the beam current or perturb the synchrotron radiations. In this paper, the narrowband impedances in the HEPS storage ring are investigated element by element.

INTRODUCTION

The High Energy Photon Source (HEPS) [1] is designed with beam energy of 6 GeV and natural emittance of less than 60 pm. The typical vacuum chamber has a circular cross section with radius of 11 mm. The full aperture at the undulators is around 5~8 mm. In addition to the small momentum compaction factor in order to reach diffraction limited emittance, the impedance can have an influence on the stationary beam parameters [2], as well as restrict the single bunch intensity [3, 4]. Meanwhile, the impedance induced transient effect during injection can also become potential restrictions to the ring injection [5]. On the other hand, the narrowband impedances generated by the discontinuity of the vacuum chamber, such as the cavities, or the resistive wall impedance in the transverse plane, can also induce coupled bunch instabilities, that will restrict the total beam current, perturb the synchrotron radiations or induce heating issues due to the parasitic power loss from the beam. Therefore, the impedance needs to be carefully modelled and well controlled.

According to the careful modelling of the ring impedance [3, 6], the dominant impedance contributors in HEPS are identified. The origins of the narrowband impedance are first identified from the impedance spectrum obtained by wake field solver. Then the field distributions and detailed information of the narrowband impedances are further studied by eigen mode solver. The dominant contributors to the narrowband impedance include the resistive wall, in-vacuum undulators, kickers, photon absorbers, RF cavities, Gate Valve, BPM & bellows assembly and DCCT.

In this paper, both longitudinal and transverse narrowband impedances of the key elements are investigated. Their potential influences to the coupled bunch instability are discussed to make sure that the instability thresholds are maintained above the operation parameters.

† email address: wangn@ihep.ac.cn

RESISTIVE WALL

The sharp resonance of the transverse resistive wall impedance at around zero frequency is one of the major contributions to transverse coupled bunch instabilities. The growth rate of the instability is mainly determined by the impedance at the frequency around the revolution frequency.

Normally, the well-known impedance formula considering infinite wall thickness [7] can well represent the resonance. However, for the circular accelerators with large circumference or for vacuum chamber with thin wall thickness, the electromagnetic field at the revolution frequency will penetrate outside the vacuum chamber. In these cases, the transverse impedance will deviate from the well-known formula and the impedance theories for finite wall thickness [8, 9] should be used.

The HEPS storage ring has a revolution frequency of 220.4 kHz. The horizontal and vertical working points are 115.15 and 104.29, respectively. So that the dominant impedance contributors to the coupled bunch instabilities are sampled at 187.3 kHz in the horizontal plane and 156.5 kHz in the vertical plane. The transverse resistive wall impedance contributed from different vacuum components are shown in Fig. 1. Here, only the vertical impedance is shown, since it is normally dominant compare to the horizontal one, due to the existence of large number of vertical insertion devices with small gap.

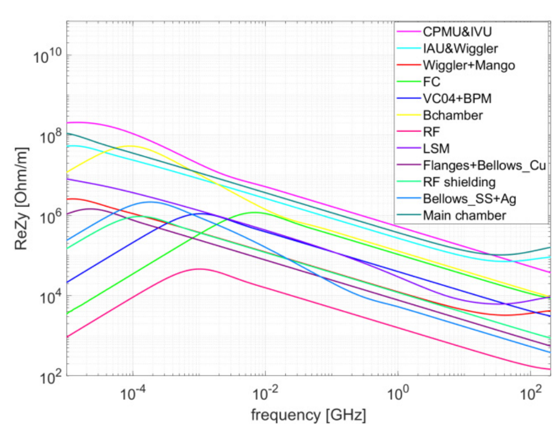

Figure 1: The real part of the vertical resistive wall impedance generated from different vacuum components.

The results show that the transverse resistive wall impedance is mainly contributed by the insertion devices, the main vacuum chamber as well as the bending magnets. With the impedance, the transverse resistive wall instability has a fastest growth rate of approximately 0.4 ms.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC58

IN VACUUM UNDULATORS

The in vacuum undulators generate vertical narrowband impedance due to the ridge waveguide structure formed by the magnetic poles and the vacuum chamber tank. The schematic view of the transverse cross section at the center of the IVU is shown in Fig.2. The transverse resonances are also measured with the coupling probes. The key parameters of the first four dominant HOMs are listed in Table 1, and compared with the simulation results. The measured frequencies of the modes show good agreement with the simulations. However, the quality factors measured are much lower than the simulations. This can be explained by the damping effect of the complex components of the structure [10]. With the measured quality factors, the shunt impedances of the resonances are evaluated. In resonant condition, the impedance is still higher than the impedance threshold given by the synchrotron radiation damping and bunch-by-bunch feedback system is needed.

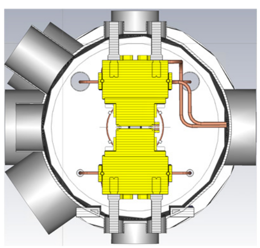

Figure 2: Transverse cross section view at the center of the IVU.

Table 1: Comparison of Measurement and Simulations on the IVU HOM Parameters

Simulation		Measurement	
f [MHz]	Q	f [MHz]	Q
74.1	2483	75.9	153
87.8	1875	88.9	268
109.6	1531	110	241
136.7	1416	136.4	329

INJECTION STRIPLINE KICKERS

The necessity of the short pulse bottom width (less than 10 ns) and strong deflection field requires the kicker to have a short length and a small gap between the electrodes, respectively. A novel five-cell stripline kicker [11] is proposed in order to save longitudinal space as well as to reduce the beam coupling impedance. The geometrical view of the kicker is shown in Fig. 3. Comprehensive studies have been undertaken to characterize the impedance of the stripline kicker [12]. Resonances are mainly generated by the gaps between the adjacent electrodes as well as that between the electrode and vacuum chamber.

Both the longitudinal and transverse impedances of the five-cell stripline kicker present TEM-mode-like resonances below ~ 4GHz. In this frequency range, the impedance behaviour is more or less identical to that of the single cell kickers, since the electromagnetic field generated by the beam is more localized. However, at frequencies above 4 GHz, the impedances are remarkably reduced in comparison to five, individual, single cell kickers, due to the mitigation of the resonant effect from the interaction among different kicker cells. The resonances are mainly concentrated above 10 GHz.

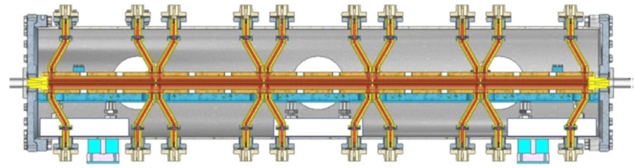

Figure 3: Longitudinal cross section along the beam axis of the five-cell stripline kicker.

DUMP KICKER

Two slot pipe kickers, as shown in Fig. 4, are used for the beam dump in machine protection. One of them is located in the vertical plane, and the other one is located in the horizontal plane, which is longer but with similar structure as in the vertical plane. Due to the non-perfect field matching at the connection between the electrodes and feedthrough, as well as the reflection from the power supply, resonances exist in the transverse plane. The dominant HOMs located below 1 GH. A batch of impedance measurements are also performed and confirmed the resonances and influence of the feedthrough terminals.

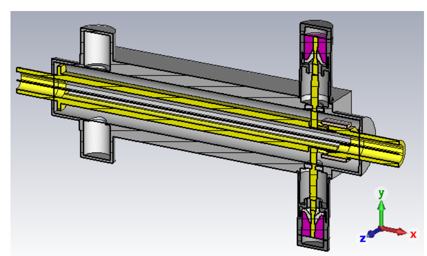

Figure 4: Longitudinal cross section along the beam axis of the vertical dump kicker.

PHOTON ABSORBERS

In order to protect sensitive components for synchrotron radiation damage, photon absorbers are commonly adopted either in the bending magnets or in the in-air undulators (IAUs). The absorbers normally located in the antechambers and intrude inside the beam pipe area. In addition, gaps are reserved in both up and down sides of each absorber to ensure that the distance between the tip of the absorber and the beam can be adjusted. Therefore, horizontal modes could be trapped between the absorber and the vacuum tank hosting them [13]. Both the impedance contributions from the absorbers in the IAUs and bending magnets are investigated. The horizontal HOMs from the absorbers are mainly focused below 2 GHz.

COLLIMATORS

Collimators are needed to scrape particles with large oscillation amplitude and control the activation or particle losses on the insertion devices, as well as in other areas of

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC58

the tunnel. To reach the requirements, the design configuration features small gaps between the collimator jaws. The collimator jaws are made of copper and located in the horizontal plane. Carbon is used on the tip of the collimator jaw since it is more robust against beam hitting. Although taper transition has been adopted on both sides of the collimator jaw, there are still trapped modes in the horizontal plane. However, the existence of carbon seems to show some detuning effect to the HOMs.

GATE VALVES

The cavity structure formed by the gate valves will be shielded by longitudinal slots, which are made of copper beryllium. The slots bend outward to ensure that they will not interact with beam by accident. The cavity formed by the bended slots introduces narrowband resonances in both longitudinal and transverse planes. Considering the large quantity of the gate valves adopted in the ring, they give the strongest longitudinal mode at around 8.5 GHz.

DIAGNOSTIC COMPONENTS

The narrowband impedance contributed by the diagnostic components, including feedback kickers, BPM and bellows assembly and DCCT, is investigated. The design of the feedback kickers has been optimized in order to mitigate their impedance contributions, especially for the narrowband resonances. The shunt impedances of the feedback kickers are all well below the CBI threshold determined by the synchrotron radiation damping. For the DCCT, due to the existence of the ceramic insertion, a resonance in the longitudinal plane exists at around 280 MHz, but well below the CBI threshold. Concerning the BPM and bellows assembly, narrowband impedances in the longitudinal plane are observed around the cut-off frequency of the vacuum chamber. The transverse modes are mainly located above 6 GHz.

SUMMARY

The narrowband impedances of the key vacuum elements in HEPS are investigated by eigen mode simulations, some of which have also been identified by the bench measurements. Figures 5-7 show the shunt impedance of the narrowband resonances in both longitudinal and transverse planes. The results are also compared with the coupled bunch instability threshold determined by the synchrotron radiation damping at different operation scenarios. In the longitudinal plane. The longitudinal HOMs are all well below the threshold with harmonic cavity, however for the cases without harmonic cavity, the HOMs from the gate valves and BPM & bellows assembly are above the threshold. In the transverse plane, there are several modes below 1 GHz exceed the CBI threshold. They are mainly contributed by the in vacuum undulators, dump kickers and photon absorbers. These modes need to be further damped by the feedback kickers.

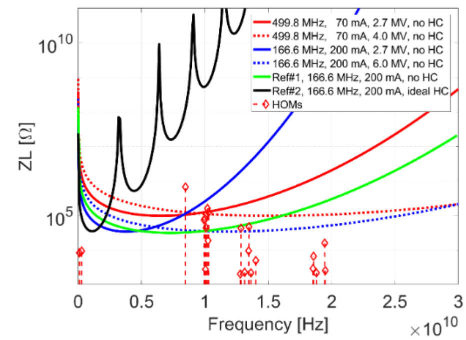

Figure 5: The shunt impedance of the longitudinal narrowband resonances, which are compared with the coupled bunch instability threshold determined by the synchrotron radiation damping at different operation scenarios (with different RF setting or beam current).

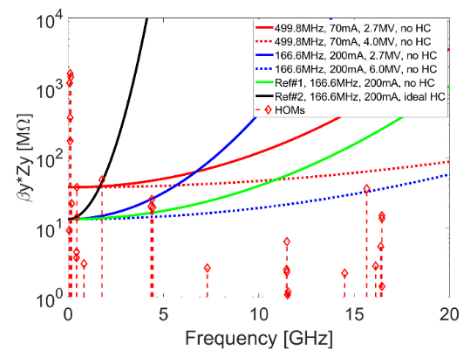

Figure 6: The shunt impedance of the vertical narrowband resonances, which are compared with the coupled bunch instability threshold determined by the synchrotron radiation damping at different operation scenarios (with different RF setting or beam current).

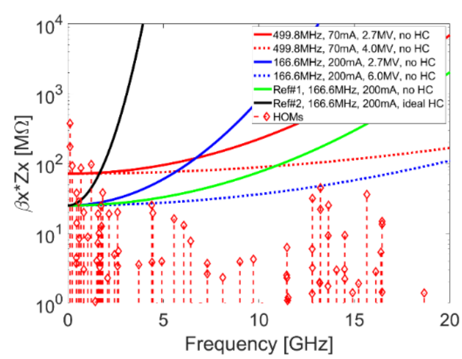

Figure 7: The shunt impedance of the horizontal narrowband resonances, which are compared with the coupled bunch instability threshold determined by the synchrotron radiation damping at different operation scenarios (with different RF setting or beam current).

ACKNOWLEDGEMENT

The authors would also like to thank the support from HEPS. The work is also supported by the NSFC (11775239), Youth Innovation Promotion Association CAS, and innovation study of IHEP.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC58

REFERENCES

[1] Y. Jiao *et al.*, “The HEPS project”, *J. Synchrotron Rad.* Vol. 25, pp. 1611-1618, 2018.

[2] H.S. Xu, C. Meng, Y.M. Peng, *et al.* “Equilibrium electron beam parameters of the High Energy Photon Source”, *Radiation Detection Technology and Methods,* Jan. 2023. doi.org/10.1007/s41605-022-00374-w

[3] N. Wang, H.S. Xu, S. K. Tian, Z. Duan, X.Y. Li, "Study of Beam Coupling Impedance and Beam Collective Effect in High Energy Photon Source", *Atomic Energy Science and Technology*, vol. 53, no. 9, 2019.

[4] H. S. Xu, J. Y. Xu, and N. Wang, “Influences of harmonic cavities on single-bunch instabilities in electron storage rings,” *Nuclear Science and Technologies,* vol. 32, no. 9. August, 2021. doi: 10.1007/s41365-021-00926-7

[5] H. S. Xu, Z. Duan, N. Wang, and G. Xu, “Mitigation of collective instability in the transient process after swap-out injection by RF modulation”, *Nuclear Inst. and Methods in Physics Research*, vol. 986, p. 164658, 2021.

[6] N. Wang, S.K. Tian, X.Y. Li, G. Xu, Z. Duan, H. Shi, “Development of the impedance model in HEPS”, in *Proc. of IPAC’17*, Copenhagen, Denmark, May 2017, pp. 3310-3113. doi: 10.18429/JACoW-IPAC2017-WEPIK078.

[7] A. Chao, Physics of Collective Beam Instabilities in High Energy Accelerators, Wiley, New York, 1993.

[8] N. Wang, Q. Qin, Resistive-wall impedance of two-layer tube, *Phys. Rev. ST Accel. Beams* 10 (2007) 111003.

[9] Nicolas Mounet, The LHC Transverse Coupled-Bunch Instability (Ph.D. thesis), Ecole Polytechnique, Lausanne, 2012.

[10] 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, p. 050702, 2019.

[11] L. Wang, J.H. Chen, H. Shi, *et al.*, “A novel 5-cell strip-line kicker prototype for the HEPS on-axis injection system”, *Nuclear Inst. and Methods in Physics Research*, vol. 992, p. 165040, 2021.

[12] N. Wang, S.K. Tian, L. Wang, H. Shi, S. Yue, G.W. Wang, and J.H. Chen, “Impedance optimization and measurements of the injection stripline kicker”, *Phys. Rev. Accel. Beams,* vol. 24, no. 3, p. 034401, 2021. doi:10.1103/PhysRevAccelBeams.24.034401

[13] J. Li, N. Wang, S. Yue, and S. Tian, “Impedance of in-air undulator vacuum chamber in HEPS,” *Journal of Instrumentation,* vol. 18, no. 12, p. P12003, Dec. 2023. doi:10.1088/1748-0221/18/12/p12003