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ESTIMATION OF IMPEDANCES AND CORRESPONDING INSTABILITIES IN KOREA-4TH GENERATION STORAGE RING

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Abstract

Due to the small vacuum apertures, impedance serves as a significant cause of beam instabilities in the 4th generation storage rings. These instabilities are directly affected by the bunch charge, thereby placing a limit on the maximum achievable beam current within the storage ring. The Korea-4th generation storage ring (Korea-4GSR) is currently under construction with the aim of reaching a maximum beam current of 400 mA. To meet this goal, we've conducted estimations and optimizations on the storage ring impedance. In this report, we show the impedance of Korea-4GSR and the corresponding instabilities.

INTRODUCTION

The Korea-4th Generation Storage Ring (4GSR), currently under construction in Ochang, South Korea, targets a beam current of 400 mA and the emittance under 100 pm [1, 2]. It features 28 hybrid 7-bend achromats and spans a total circumference of 800 meters. The design includes 26 straight sections, each approximately 6 meters in length, along with two high-beta sections. The initial installation will include seven 3-meter-long in-vacuum undulators (IVUs), two elliptical polarized undulators, and one bending source beamline. The Korea-4GSR has the capacity to support up to 22 insertion devices and 28 bending sources.

Low-emittance storage rings face instability issues due to small apertures and high current operation. These induce strong impedance that influences beam stability and emittance [3–6]. The Korea-4GSR, with its target beam emittance below 100 pm and the current of 400 mA distributed uniformly across 1020 bunches, also encounters these challenges. The impedance modeling and corresponding instabilities are being prepared for Korea-4GSR.

In this report, we first present the status of impedance modeling of the Korea-4GSR. Following this, we briefly estimate the beam current threshold for single-bunch instabilities using numerical tracking simulations.

KOREA-4GSR IMPEDANCE MODELING

The design and impedance modeling of the Korea-4GSR are currently in progress. The present report does not account for all components, such as collimators and diagnostic devices, which will be included in future updates. For the current calculations, those components have been replaced with similar ones or not accounted for.

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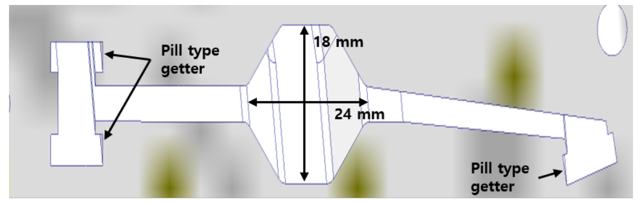

Figure 1: Vacuum chamber at arc section. Octagonal beam channel with 24 mm horizontal width and 18 mm vertical width.

Resistive wall (RW) impedances were calculated using ImpedanceWake2D [7]. The vacuum chambers cross sections are octagonal beam channel with an antechamber for pumping and synchrotron radiation (see Fig. 1) [8]. Most photon absorbers are placed in the antechamber 17 mm away from the beam to minimize the impedance induced. Fill type NEG getters are placed in the antechambers such that there are no NEG coated chambers in Korea-4GSR.

For RW impedance calculation, this octagonal chamber was approximated as an ellipse with a semi-major axis of 10 mm and a semi-minor axis of 9 mm. At the center bend, the vertical width of the chamber is reduced from 18 mm to 9.74 mm while the horizontal width remains consistent. Most chambers will be fabricated from aluminum, but some will be made from stainless steel for mechanical reasons. In the injection section, four titanium-coated ceramic chambers with length of 0.64 m will be installed for four kicker bump injections. Table 1 summarizes the materials and corresponding lengths used in the storage ring.

Table 1: Korea-4GSR Component Materials

Material	Length
Aluminum	634.21 m
Stainless steel	82.52 m
Copper	80.05 m
Ti coated ceramic	2.52 m
Total	799.3 m

Geometric impedances were calculated using GdfidL [9] to estimate cross-section variations inside the components. The simulations were performed with a bunch length of 1 mm for numerical particle tracking, as well as loss and kick factor calculations. The loss, kick parameters, and effective impedance of each component are listed in Table 2.

For Korea-4GSR, the longitudinal loss factor κ_z is 43.97 V/pC and the effective impedance Z/n_{eff} is

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Table 2: Loss, kick parameters and effective impedances of Korea-4GSR components. Used RMS bunch length is 3.6 mm and assumed 22 IVU are opened with vertical gap of 16 mm. K_x and K_y are $< \beta_x > \kappa_x$ and $< \beta_y > \kappa_y$, respectively.

Components	Number	κ_z [V/pC]	$< \beta_x >$ [m]	K_x [V/pC]	$< \beta_y >$ [m]	K_y [V/pC]	Z/n_{eff} [mΩ]
RW	1	13.00	16.01	7870.04	4.86	38040.39	234.49
Main RF cavity	10	12.20	16.01	1208.78	4.86	366.93	51.42
BPM	288	8.36	4.05	5570.94	4.15	5715.55	47.46
Gate valve	80	4.70	6.60	2434.08	3.65	2432.36	32.26
Bellows	279	2.20	4.15	2663.06	6.47	2310.57	17.86
Long. feedback kicker	1	1.67	6.60	711.61	3.65	419.57	5.37
LGBM chamber	28	0.76	0.98	346.51	21.41	-2967.43	4.09
RF taper	6	0.65	16.01	894.32	4.86	728.42	11.34
Pump screen	84	0.61	3.92	3434.39	3.47	-1154.26	11.17
Absorber RF	5	0.52	16.01	647.44	3.47	-100.41	3.80
Hor. feedback kicker	1	0.21	6.60	7.46	3.65	151.58	0.65
Ver. feedback kicker	1	0.21	6.60	274.10	3.65	4.12	0.65
IVU taper open	22	0.04	6.60	-124.67	3.65	261.56	16.49
Flange joint	728	0.04	7.00	2.31	7.37	6.04	14.27
Arc chamber	28	0.10	1.09	-124.95	2.36	2991.71	8.68
Total	-	43.97	-	25815.38	-	49206.70	431.95

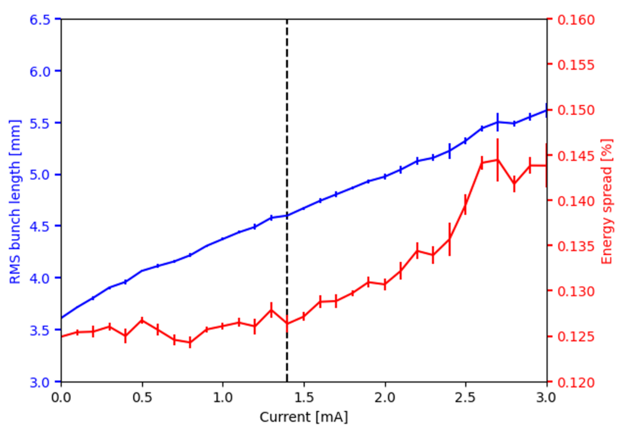

Figure 2: Microwave instability simulation with PyAT. Blue line indicates RMS bunch length and red line is energy spread. Black Dashed line is microwave instability threshold line.

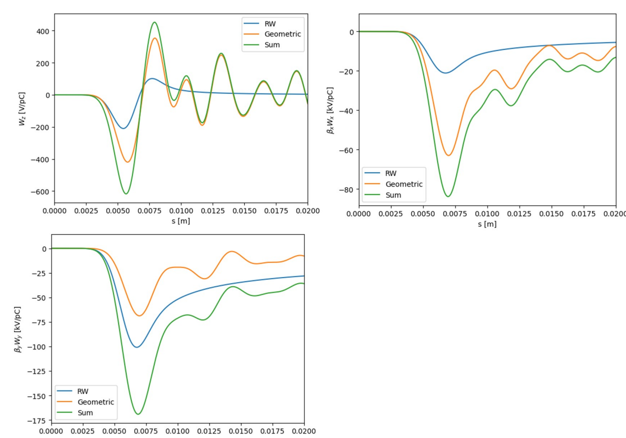

Figure 3: Longitudinal Wake potentials and beta-weighted transverse wake potentials with longitudinal bunch length of 1 mm.

431.95 mΩ. The RW impedance constitutes a large portion of the total impedance due to the 800 m circumference and the octagonal cross-section with a radius of 9 mm. 500 MHz main RF cavities, BPM, gate valve, and bellows are major sources of geometric impedance. The longitudinal gradient dipole magnet (LGBM) chamber also induces some impedance because the photon absorber invades the beam channel.

For the contribution from RF cavities, only 500 MHz higher-order mode (HOM) damped cavities are considered. However, Korea-4GSR plans to install 3rd harmonic cavities to increase the bunch length from 3.6 mm to 14 mm. Bunch lengthening will increase the Touschek lifetime and reduce impedance effects, while transient beam-loading issue arise from the harmonic cavity.

SINGLE BUNCH INSTABILITIES

The baseline operation mode for Korea-4GSR is 400 mA uniform filling with 1020 bunches, corresponding to a single bunch current of 0.392 mA (1.046 nC). In order to meet various user demands, hybrid and timing modes are under discussion. Therefore, we need to understand the single bunch instabilities' threshold currents. Single bunch simulations were performed with the estimated impedance modeling. The numerical particle tracking code Python Accelerator Toolbox (PyAT) [10] was used, which requires the wake function for collective simulations. Figure 2 shows the RMS bunch length and energy spread depending on the single bunch current. The simulations include 10,000 particles and 20,000 turns with longitudinal wake potentials, as shown in Fig. 3. The RMS bunch length and energy spread for the

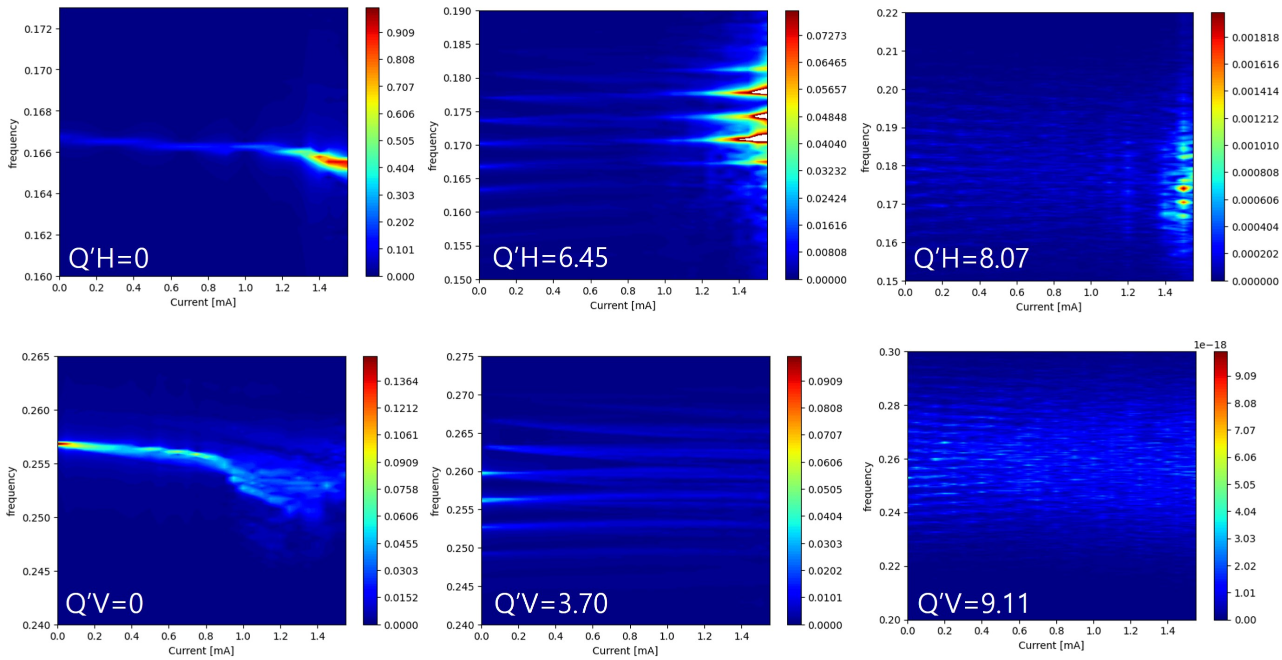

Figure 4: Transverse tune shift simulation with different chromaticities. Three simulations were performed, Q'H, Q'V = (0, 0), (6.45, 3.70), and (8.07, 9.11).

last 500 turns were averaged, with error bars representing the standard deviation of the 500 turns. The energy spread starts to increase at a current of 1.40 mA (3.66 nC), which is the threshold for microwave instability [11].

Transverse simulations were performed to analyze transverse mode coupling instability (TMCI) [11]. Transverse wake potentials in Fig. 3 were implemented in PyAT simulations. For chromaticities, three sets of horizontal Q'H and vertical Q'V chromaticities were used: zero chromaticities, current ring nominal chromaticities, and chromaticities optimized for long Toushek lifetime. In Fig. 4, the tune shift due to transverse impedance was simulated with the three different sets of chromaticities. Because Korea-4GSR has an octagonal-shaped vacuum chamber, quadrupole impedance remains in the transverse planes. In the horizontal plane, dipolar and quadrupole impedances cancel each other out, while in the vertical plane, they do not [12]. TMCI appears at a current of 1.2 mA in the horizontal plane and 0.93 mA in the vertical plane. However, TMCI in the vertical plane disappears in the scanned range of 1.5 mA for Q'V of 3.7 and 9.11. In the horizontal plane, Q'H of 6.45 and 8.07 show an improvement in the TMCI threshold current.

CONCLUSION

We are constantly updating the impedance model of Korea-4GSR. In this paper, the impedance modeling is incomplete with some missing components. However, the major sources of the ring impedance have been estimated. The modeled impedances are sufficient for a brief estimation of single bunch instabilities. Both MWI and TMCI were explored. The results show that the MWI current threshold is 1.40 mA and the TMCI threshold is 0.93 mA for zero chromaticity, which can be improved by increasing chromaticity.

The single bunch instability estimations were performed with a bunch length of 3.6 mm, while Korea-4GSR will adopt the harmonic cavities to increase the bunch length to 14 mm. This will definitely reduce the impedance effects. The next step is finding instability thresholds in the case of ID open, ID close with and without the harmonic cavity.

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