IMPEDANCE AND COLLECTIVE EFFECTS FOR THE ADVANCED LIGHT SOURCE UPGRADE AT LBNL*

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Abstract

The upgrade of the Advanced Light Source (ALS-U) consists of a multiband achromat ultralow emittance lattice for the production of diffraction-limited soft x-rays. A very important issue for ALS-U is represented by instabilities induced by wakefields, that may limit the peak current of individual bunches and the total beam current. In addition, vacuum chamber apertures of few millimeters, that are a key feature of low-emittance machines, can result in a significant increase in the Resistive Wall (RW) impedance. In this paper we present progress on establishing short range wakefield model for ALS-U and evaluating the impact on the longitudinal and transverse single bunch dynamics.

INTRODUCTION

ALS-U is the proposed upgrade to the Advanced Light Source (ALS) at LBNL [1]. Operating at beam energy of 2 GeV and current of 500 mA, it is of fundamental importance to study the ALS-U beam dynamics under the influence of wakefields. For this purpose, performing simulation with particle dynamic tracking codes is usually a valid approach. However, simulation codes take as input the Green function, that is the wakefield produced by a point charge, while wakefield solvers as CST Particle Studio [2] produce the wake potential of a Gaussian distribution. A solution to this problem is to calculate the wake potential with CST Particle Studio for a value of bunch length much smaller with respect to the design value. When the wake is computed for all the components of the ring, a total short range wakefield model of the machine is obtained by summing the individual contributions. The resulting short range wake potential can be considered as a pseudo-Green function. Once the total pseudo-Green function is known, it can be used as input for tracking simulation codes, allowing for a realistic estimation of the single bunch instability thresholds. In this paper we present the short range wakefield calculations that have been performed with CST Particle Studio for the main components of the ring. We obtained a pseudo-Green function on the longitudinal and transverse plane and applied it as input of single bunch instabilities simulations.

SHORT-RANGE IMPEDANCE MODEL

Resistive Wall

To compute the RW impedances and wakes, we considered a model of the ALS-U circular copper vacuum chamber, coated with a 1 μm thickness layer of NEG, consisting of three different radii: 3.5 mm for the insertion devices in the straight sections (total length 62.88 m), 10 mm radius in matching sections (total length 72.60 m) and 6.5 mm in the arcs (total length 60.96 m). Longitudinal and transverse RW impedance has been computed with the code IW2D developed at CERN [3]. More details of the ALS-U RW impedance studies can be found in [4]. While the longitudinal RW impedance is inversely proportional to the beam pipe radius, the transverse impedance has a strong third-power scaling with the inverse of the radius. We expect the RW impedance, especially the contribution coming from the insertion device, to strongly impact the transverse single bunch instabilities.

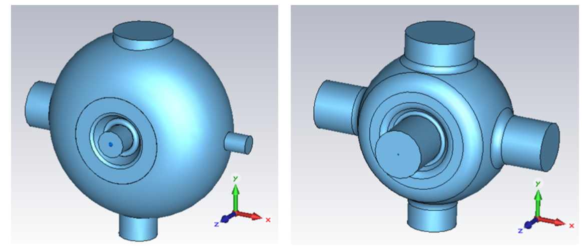

Figure 1: 3D models used for CST impedance simulations of the main cavity (left) and harmonic cavity (right).

RF Cavities

The current plan for the ALS-U is to reuse the ALS 500 MHz normal conducting main and third harmonic cavities. The harmonic cavity is designed to provide bunch lengthening to reduce the intra beam scattering (IBS), to achieve the desired ultralow transverse emittance and increase the Touschek lifetime. Impedance studies have been performed with CST Particle Studio. In Fig. 1, the two geometries of the cavities used for impedance simulations with CST Particle Studio, equipped with HOM ports and tuners, are shown. The two models are not to scale: the main cavity has an internal radius of 290 mm and a beam pipe of 35 mm, while the harmonic cavity has an internal radius of 78 mm and beam pipe of 25 mm radius. In this model we did not included the transitions from the cavities beam chamber to the very narrow vacuum chamber in the straight section (3.5 mm radius). The longitudinal and transverse short range wakes have been computed with CST Particle Studio for both geometries, using a bunch length of 0.3 mm and 1 mm, respectively. The loss factor and the transverse kick factor computed for the design bunch length of 13 mm, are summarized in Table 2.

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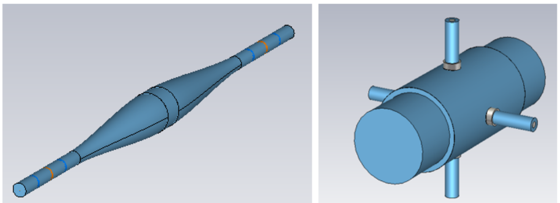

Figure 2: 3D models used for CST impedance simulations of the large ID BPM (left) and the small ID taper transition (right). The models are not to scale.

Tapered Transitions

A significant source of impedance of ALS-U is due to the transitions between beam chambers of different radius. Current space constraints and impedance concerns in ALS-U require a smooth, tapered transition of 70 mm length. Other transition lengths have been previously considered and discussed in [4] . Two types of tapered transitions are currently foreseen in ALS-U: we are referring as small ID taper the transition between the straight section and the matching section (10 mm-3.5 mm aperture), and as large ID taper the transition between the matching section and the arc (10 mm-6.5 mm aperture). Most of the 3D particle simulation code available cannot be used when the beam entrance cross-section is different from the beam exit cross-section. To overdue this problem, we used the model of Fig. 2 (left). By scaling the result of the simulation by a factor 12 (corresponding to the number of sectors in the machine), we account for all the transitions predicted in ALS-U. We chose to connect the two tapers in the model with a beam tube of 10 mm length: we observed that changing the length of the connecting tube is not impacting the results in terms of the short range wake. Therefore, we chose 10 mm in order not to increase excessively the total longitudinal dimension of the structure and, as a consequence, the computation time. We use the same approach for the large ID taper transition. The longitudinal and transverse short range wakes have been computed with CST Particle Studio, using a bunch length of 0.3 mm and 1 mm, respectively. The loss factor and the transverse kick factor are summarized in Table 2.

Beam Position Monitors

Impedance studies have been performed for the preliminary design of the capacitive button BPMs. The design has been scaled and adapted to the ALS-U ring from the models used in the MAX IV storage rings [5]. Two types of BPMs are currently foreseen in ALS-U: we refer as small ID the BPM installed in the arc (radius 6.5 mm), and as large ID the BPM installed in the matching section (radius 10 mm). In the small ID, the four electrodes are placed at 45° and connected to a vacuum tube of 7.56 mm radius and 30.12 mm length. The button radius is 1.47 mm. The tube is then connected to the arc beam chamber through a step transition. In the large ID, the four electrodes are placed at 45° and connected to a vacuum tube of 11.36 mm radius and 37 mm length. The button radius is 2.27 mm. The tube is then connected to the matching section beam chamber through a step transition. In Fig. 2 (right), the model of the large ID BPM used for CST simulations, is shown. In total, we predict to install 120 large ID and 72 small ID BPMs. Due to the large number of element foreseen, we expect the BPMs to be one of the most critical contributors to the impedance budget. The longitudinal and transverse short range wakes have been computed with CST Particle Studio, using a bunch length of 0.3 mm and 1 mm, respectively. The loss factor and the transverse kick factor are summarized in Table 2.

Table 1: Loss Factor and Transverse Kick Factor for the Components of ALS-U, Computed at the Design Bunch Length of 13 mm

Component	N	$k_{//}$ [V/pC]	$k_{\perp}$ [V/pC/mm]
Main cavity	1	0.650	$9.709 \cdot 10^{-3}$
Harmonic cavity	2	0.904	$1.773 \cdot 10^{-2}$
BPM (Small ID)	72	$2.171 \cdot 10^{-4}$	$6.428 \cdot 10^{-3}$
BPM (Large ID)	120	$2.103 \cdot 10^{-5}$	$2.980 \cdot 10^{-3}$
Taper (Small ID)	12	$5.027 \cdot 10^{-4}$	$1.342 \cdot 10^{-2}$
Taper (Large ID)	12	$4.552 \cdot 10^{-4}$	$4.017 \cdot 10^{-3}$
Resistive wall	1	0.401	2.260

LONGITUDINAL SINGLE-BUNCH INSTABILITY

To compute the bunch lengthening and the microwave instability threshold in ALS-U we used the Elegant [6] computer simulation tracking code. Some key simulation parameters are summarized in Table 2.

Table 2: Main ALS-U Parameters for Elegant Simulations

Energy [GeV]	2.00
Machine length [m]	196.5
Momentum compaction	2.79e-04
Energy spread	8.00e-04
Bunch length [mm]	12.95
Main RF voltage [kV]	760
Harmonic voltage [kV]	245
Main RF synch. phase [deg]	164
Harmonic synch. phase [deg]	354
$\beta_{x,y}$	2.147-2.912
Tune $\nu_{x,y}$	41.364 - 20.368

The longitudinal presudo-Green function has been computed with a bunch length of 0.3 mm, that is about 1/40 of the ALS-U design bunch length of 13 mm, and it is shown in Fig. 3. It includes the contributions of cavities, tapers and BPMs. The RW longitudinal impedance, computed with IW2D, is defined in a separate input file. For Elegant simulations, 130'000 macroparticles and 40'000 turns have been

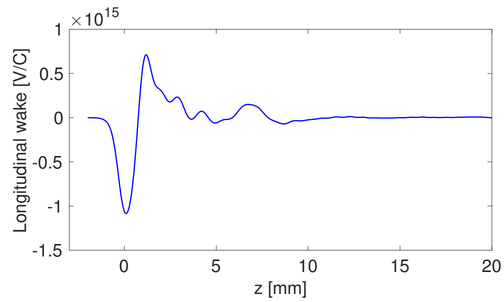

Figure 3: ALS-U longitudinal pseudo-Green computed with CST Particle Studio and σ=0.3 mm.

used. The ALS-U bunch length and energy spread evaluated at different beam current values are shown in Fig. 4. The scan in current has been performed up to 3 mA, showing an increase of energy spread from $8.37{\cdot}10^{-4}$ to $8.89{\cdot}10^{-4}$. The bunch length is increasing with beam current, starting from 13.39 mm at zero current to 14 mm at 3 mA.

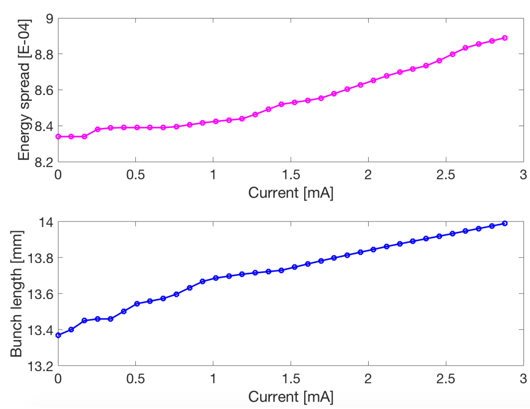

Figure 4: ALS-U energy spread and bunch length as a function of the beam current, computed with Elegant using the short range longitudinal wake and RW impedance as input.

TRANSVERSE SINGLE-BUNCH INSTABILITY

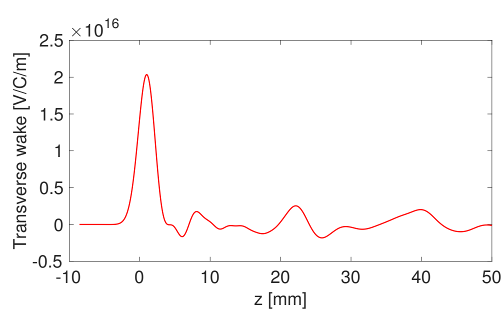

Figure 5: ALS-U transverse pseudo-Green function computed with CST Particle Studio and σ=1 mm.

To establish a threshold of the transverse mode coupling (TMCI) instability, Elegant simulations have been performed using 2'000 macroparticles and 36'000 turns on the vertical plane. The transverse presudo-Green function has been computed with a bunch length of 1 mm, that is about 1/10 of the ALS-U design bunch length of 13 mm, and it is shown in Fig. 5. It includes the contributions of cavities, tapers and BPMs. The RW transverse impedance, computed for IW2D and weighted for the β function of the ALS-U lattice, is defined in a separate input file. The scan in current has been performed up to 45 mA. Setting the vertical chromaticity to zero, and monitoring the vertical oscillations of the centroid and the bunch transverse size while increasing the current, we establish the TMCI threshold at 2.4 mA when we only use the RW impedance as input, and 1.9 mA when we use both the RW impedance and the wake function accounting for the contribution of the other elements. The same analysis has been performed changing the vertical chromaticity in the range 0-6. As show in Fig. 6, the TMCI threshold current is increasing with the vertical chromaticity.

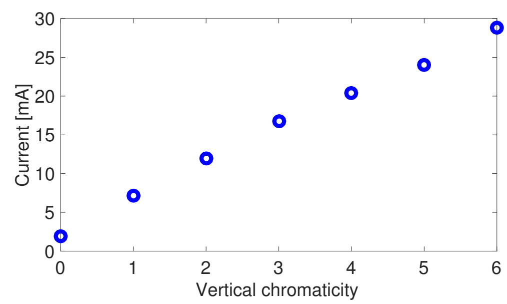

Figure 6: ALS-U TMCI threshold current as a function of the vertical chromaticity, computed with Elegant using the short range transverse wake and RW impedance as input.

CONCLUSIONS

A longitudinal and transverse pseudo-Green function has been computed for ALS-U with CST Particle Studio and a bunch length much smaller with respect to the design value. It includes the contribution of cavities, BPMs and tapers. A RW impedance model has been established considering the contribution of NEG coating and the different chamber sizes. The pseudo-Green functions and the RW impedance have been used as input for single bunch instabilities simulations in Elegant. More studies are ongoing to include other relevant machine elements and further investigate the instability thresholds.

ACKNOWLEDGEMENTS

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REFERENCES

[1] C. Steier *et al.*, "ALS-U: a soft X-ray diffraction limited light source", Proc. of NAPAC'16, paper TUB1CO03.

[2] `https://www.cst.com/`

[3] N. Mounet, "Impedances of two dimensional multilayer cylindrical and flat chambers in the non-ultrarelativistic case", Proc. of HB2010, paper TUO1C02, p. 353.

[4] S. Persichelli *et al.*, “A preliminary beam impedance model of the Advanced Light Source upgrade at LBL”, Proc. of NA-PAC’16, paper THPOA33.

[5] A. Olmos *et al.*, “BPM design for the ALBA synchrotron”, Proc. of EPAC 2006, paper TUPCH078, p. 1190.

[6] M. Borland, “elegant: A flexible SDDS-compliant code for accelerator simulation,” Advanced Photon Source LS-287, September 2000.