A PRELIMINARY BEAM IMPEDANCE MODEL OF THE ADVANCED LIGHT SOURCE UPGRADE AT LBL*

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Abstract

The proposed upgrade of the Advanced Light Source (ALS-U) consists of a multi-bend achromat ultralow emittance lattice optimized for the production of diffraction-limited soft x-rays. A narrow-aperture vacuum chamber is a key feature of the new generation of light sources, and can result in a significant increase in the beam impedance, potentially limiting the maximum achievable beam current. While the conceptual design of the vacuum system is still in a very early development stage, this paper presents a preliminary estimate of the beam impedance using a combination of electromagnetic simulations and analytical calculations. We include the impedance of cavities, select vacuum-chamber components and resistive wall in a multi-layered beam chamber with NEG coating.

INTRODUCTION

ALS-U is a proposed upgrade to the Advanced Light Source (ALS) at LBNL. Operating at beam energy of 2 GeV and current of 500 mA, the intent of ALS-U is to produce soft x-ray coherent flux that is orders of magnitude higher than at the existing machine at LBNL and well beyond the coherent flux at any operating light source. The upgrade program includes the replacement in the storage ring of the existing triple-bend achromat with a multi-bend achromat lattice, keeping the same footprint, symmetry and length of the straight sections of ALS. Moreover, a new low emittance accumulator ring will be installed in the existing tunnel, with the purpose of enabling swap-out injection using fast magnets. In order to improve the performances of insertion devices and allow for the larger focusing gradients needed for low emittance, extremely small vacuum chamber apertures are a key feature of ALS-U which will enhance the sensitivity to instabilities driven by collective effects. In this paper we start to address the problem by calculating the beam coupling impedance contributed by the resistive wall, main and harmonic cavities and the vacuum-chamber egresses collecting the radiation fan from the undulators.

RESISTIVE WALL

In ALS-U, the triple-bend achromat magnetic lattice of ALS is replaced with a stronger focusing multi-bend achromat. The high focussing strength and compact magnet design is achieved by using a small circular, or nearly circular, vacuum chamber of the order of 10 mm radius or less. The

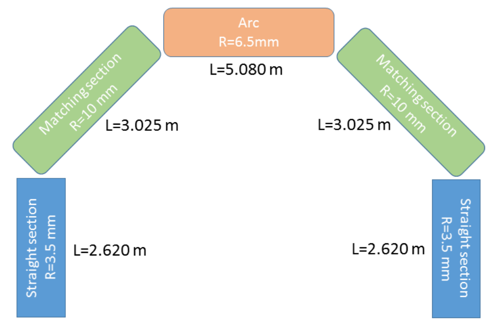

Figure 1: A sketch of an ALS-U sector.

limited conductance and pumping speed is mitigated by using non-evaporable getter (NEG) coated vacuum chambers. The vacuum chamber of ALS-U is designed with apertures about 2.5 times smaller than the current ALS in the vertical direction and much smaller in the horizontal. Therefore, the transverse resistive wall (RW) impedance is expected to be critical for the new machine performance. Ensuring good vacuum will require NEG coating ideally in the whole machine. In this approach, the whole vacuum chamber acts like a fully distributed vacuum pump, achieving good vacuum pressures with the small apertures required from ALS-U.
In this section we are presenting the results of resistive wall impedance calculations, taking into account the effect of the NEG coating. To this end, we considered a simplified model of the ALS-U circular vacuum chamber 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). A sketch of an ALS-U sector is shown Fig. 1. It is worth noting that 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. Due to the very small radius of the chamber, we expect the insertion device sections to have a dominant impact in the transverse impedance budget. Longitudinal and transverse RW impedance has been computed with the code *ImpedanceWake2D* developed at CERN [1]. The code calculates coupling impedances and wake functions in multilayer axi-symmetric two-dimensional structures. We considered a round vacuum chamber made of copper, coated with a 1 μm thickness layer of NEG. Resistivity of copper is $1.7{\cdot}10^{-8}$ Ωm, while the NEG resistivity is assumed to be $1.5\text{e}{\cdot}10^{-6}$ Ωm [2]. In Figures 2 and 3, the real and imaginary part of the longitudinal and transverse RW impedance are shown. At the nominal ALS-U bunch length of about 200 ps, the imaginary part of the longitu-

* Work supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231
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dinal impedance is 64 Ω, while the imaginary part of the transverse impedance is 487 kΩ/m.

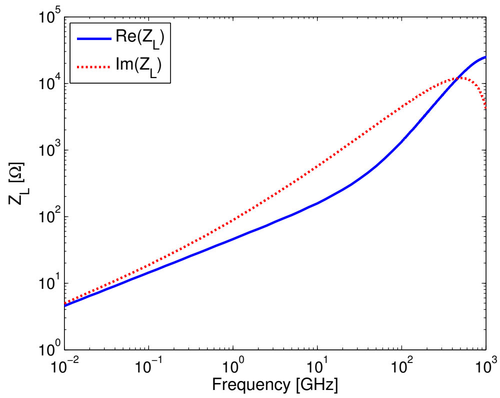

Figure 2: ALS-U total RW longitudinal impedance.

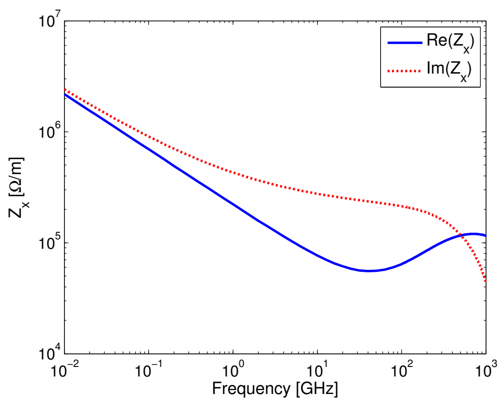

Figure 3: ALS-U total RW transverse impedance.

RF SYSTEM

The current plan for the ALS-U is to reuse one of the two existing 500 MHz normal conducting main cavities and two of the three third harmonic cavities operating at 1500 MHz [3] [4]. The second 500 MHz cavity will be installed in a new accumulator ring. A new lower frequency RF system with the existing 500 MHz system as a harmonic RF is under consideration. In general, particle scattering effects are critical in low-emittance rings because of the small bunch lengths and the high electron density. In ALS-U, the harmonic system 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. Longitudinal multibunch instabilities in ALS-U are expected to be driven primarily by the higher order modes of the RF system [5]. For this reason, an accurate impedance model has to be established for the two cavities. An instability-mitigating strategy will almost certainly have to involve a dedicated feedback system as in the current ALS. Impedance studies of the main cavity and harmonic cavities have been performed with CST Particle Studio [6] and ACE3P [7]. The cavities beam tubes are going to be

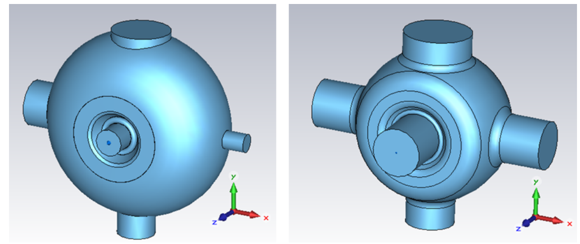

Figure 4: 3D models used for CST impedance simulations of the main cavity (left) and harmonic cavity (right).

adapted to the new machine chambers through tapered transitions. In Fig. 4, the two geometries of the cavities used for impedance simulations, 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. We first computed the longitudinal low-frequency limit of the Z/n for the main cavity from the slope of the imaginary part of the longitudinal impedance as a function of frequency (below 250 MHz the longitudinal impedance is purely inductive). For Z/n we calculated 645 mΩ for the naked cavity, and 663 mΩ for the cavity equipped with HOM ports and tuners, and connected to the 6.5 mm radius chamber with a tapered smooth transition of 120 mm length. The low frequency transverse dipolar impedance is 3 kΩ/m for the naked cavity and 7.3 kΩ/m for the full cavity. We then computed Z/n for the harmonic cavity with the same method. Below 800 MHz the longitudinal impedance is purely inductive, leading to a Z/n=139 mΩ for the cavity equipped with HOM ports and tuners. The low frequency transverse impedance is 3.2 kΩ/m. In this case, we did not consider the effect of the transitions. As expected, the Z/n impedance of the harmonic cavity is much smaller than that of the main cavity, due to its reduced volume. Also the transverse impedance is smaller because we did not account for the presence of the taper. However, there will be two harmonic cavities vs. one main cavity. These numbers should provide a useful baseline against which to gauge the relevance of the impedance contributed by additional vacuum-chamber components. In Fig. 5, the short-range wake functions of the main and harmonic cavity, calculated with CST Particle studio with a bunch length of 2 mm, are shown. These curves will be used as an input for beam dynamics and instabilities studies. The single bunch loss factor computed from CST is 1.35 V/pC for the main cavity and 1.30 V/pC for the harmonic cavity. Results from CST simulations have been benchmarked with the code ACE3P, showing a very good agreement in the computation of the wake functions and the loss factors.

VACUUM CHAMBER EGRESSES

Impedance studies have been performed for the preliminary design of the ALS-U x-ray egresses, that are foreseen to extract the radiation off the undulators, for a total of 10 elements. In Fig. 6, the model of the egress used for impedance

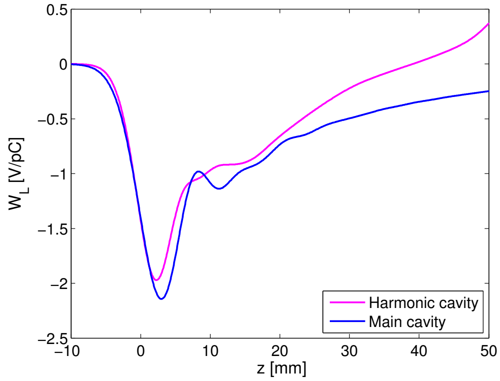

Figure 5: Wake functions of the main and harmonic cavities, calculated with CST Particle studio with a bunch length of 2 mm and wakelength of 500 mm and 150 mm, respectively.

simulations with CST Particle Studio, is shown. A taper transition of 30 mm length is considered for connecting the egress chamber of 10 mm radius with the arc of 6.5 mm radius. The same taper transition has been considered also at the beam entrance. Each egress is designed as a wide rectan-

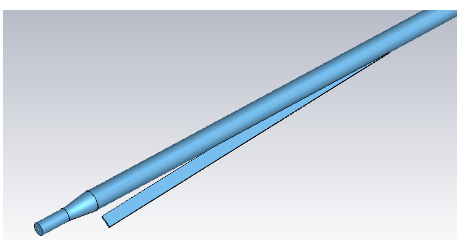

Figure 6: 3D models used for CST impedance simulations of the ALS-U x-ray egress.

gular aperture in a beam chamber of 10 mm radius (200 mm on the longitudinal axis of the beam chamber, 2 mm on the vertical axis). Z/n, computed with CST Particle Studio, is 1.008 mΩ for the single egress (including the two tapers), and about 10 mΩ for 10 elements, that is far below the Z/n of the RF cavities. The horizontal low frequency impedance is about 1 kΩ/m for the single egress. A not negligible source of impedance is due to the transitions between the beam chamber of 6.5 mm radius and 10 mm radius. While a long and smooth tapered transition is usually preferred for impedance purposes, space constraints in ALS-U require a transition of 30 mm length, or shorter. The longitudinal and transverse impedances have been computed with CST Particle Studio, considering several possible lengths of the transition. In Table 1, the impedance of different length transitions is summarized. Even if the impedance of a single transition is predicted to be negligible in comparison with the impedance of the cavities, there will be quite a few of them and care should be taken to design and model them properly. If we account for 24 step transitions (12 arcs in the ring), we obtain a Z/n of 60 mΩ, that is almost comparable to the impedance of the harmonic cavity. If we consider, instead, 24 tapered transitions of total length 30 mm, the

Table 1: Low Frequency Longitudinal and Transverse Impedances Computed for Different Length of the Transitions (0 mm corresponds to a step transition)

Length [mm]	Z/n [mΩ]	Z_x [kΩ/m]
0	2.4960	2.165
10	1.1853	0.872
20	0.7152	0.538
30	0.5151	0.433

Table 2: Preliminary estimates of the low-frequency longitudinal and transverse impedance.

	Z/n [mΩ]	Z_x [kΩ/m]
24 tapers (30 mm)	13	10.4
10 egresses	10	9.3
2 harmonic cavities	280	6.4
Main cavity	663	7.3

Z/n is predicted to be far below the value computed for the harmonic cavity, and with a factor 5 reduction in both longitudinal and transverse impedance with respect to the step transition case. Our preliminary impedance estimates for ALS-U for the various components we have considered, are summarized in Table 2.

CONCLUSIONS

A preliminary impedance model of ALS-U has been calculated with the help of analytical models and electromagnetic simulations. The model includes the contribution of the RF system, the vacuum chamber egresses and the resistive wall, taking into account the different dimensions of the beam chambers and the presence of the NEG coating. Due to the reduced dimension of the beam chambers, the transverse resistive wall impedance is expected to dominate the other sources of impedance of the machine. The short-range wake functions we calculated will be used as input for studying single-bunch instabilities. More studies are ongoing to include other relevant machine elements.

ACKNOWLEDGEMENTS

The authors acknowledge the ALS-U vacuum team for the helpful discussions.

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