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THE BROAD-BAND IMPEDANCE BUDGET IN THE STORAGE RING OF THE ALS-U PROJECT*

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Abstract

Design work is underway for the upgrade of the Advanced Light Source (ALS-U) to a diffraction-limited soft X-rays radiation source. Like other 4th-generation light source machines, the ALS-U multiple-bend achromat storage-ring (SR) is potentially sensitive to beam-coupling impedance effects. This paper presents the SR broad-band impedance budget in both the longitudinal and transverse planes. In our modeling we follow the commonly accepted approach of separating the resistive-wall and the geometric parts of the impedance, the former being described by analytical formulas and the latter obtained by numerical electromagnetic codes (primarily CST Studio software) assuming perfectly conducting materials. We discuss the main sources of impedance. Results of our analysis are the basis for single bunch instability study and would feedback on the design of critical vacuum components.

RESISTIVE WALL IMPEDANCE

ALS-U is to upgrade the existing Advanced Light Source (ALS) at LBNL to a diffraction-limited soft X-rays radiation source [1]. One of the significant factors potentially limiting performance in a ring is the beam's interaction with electromagnetic fields induced in a vacuum chamber by the beam itself, which is described with short-range wakefield (time domain) or, equivalently, broad-band impedance (frequency domain). The total impedance budget comes from the resistive wall impedance and the geometry impedance [2, 3].

To build a relatively accuracy resistive wall impedance modeling, we have go through the details of the vacuum chamber, which includes the arc chamber shown in Fig. 1 (Table 1), and the straight sections shown in Fig. 2 (Table 2).

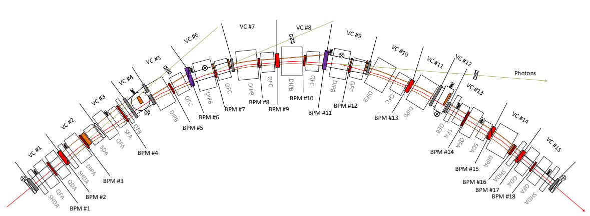

Figure 1: Layout of the normal arc and match section in the storage ring.

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Table 1: Breakdown of Sr Sector Vacuum-Chamber: Arc and Matching Sections, See Fig. 1

Type	ID Aperture (mm)	Cross Section	Total Length (m)
Matching-1	20	circular	13.92
Matching-2	20	circular	20.19
ID extraction	20	arc-keyhole	20.49
pump/gauge	20/13	circular	5.40
BM extraction	13	ante-chamber	28.13
High heatload	13	circular	45.90

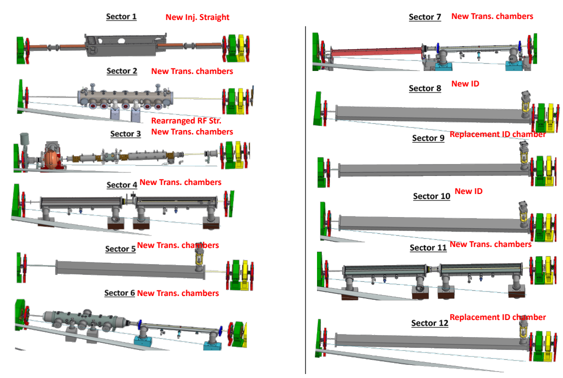

Figure 2: Layout of insert devices in the straight sections.

Table 2: Breakdown of Sr Sector Vacuum-Chamber: Insert Devices in the Straight Section, See Fig. 2

Type	ID Aperture (mm)	Cross Section	Total Length (m)
Kicker	6 (y)× 60 (x)	stripline	2
LEDA	4.1 (y)× 130 (x)	plate	9.8
EUP	10 (y)× 100 (x)	keyhole	7.4
Wiggler	10 (y)× 150 (x)	keyhole	3.3
Keyhole	10 (y)× 60 (x)	keyhole	3.43
Ellipse-1	7 (y)× 60 (x)	ellipse	2.1
Ellipse-2	10 (y)× 60 (x)	ellipse	8.7
New ID	6.0	circular	4.2
other part	20	circular	20.3

Besides the details list in Tables 1 and 2, we separately count the super-bend dipole chamber in the untypical arc sectors with a ID aperture of 4 mm $(y)\times$ 13 mm (x), which cross section is elliptical shape and the total length is 1.46 m with materials of copper with NEG coating. And in the straight section, we count section 3 (i.e., the RF section), as in the other part in Table 2 to simplified the model for resistive wall impedance.

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For the vacuum chamber in the SR we use the segmentation concept involving three materials (Cu, Al, and stainless steel, with $\sigma_c = 5.8 \times 10^7$, 1.7×10^7, and 1.3×10^6, respectively) and also the NEG coating with $\sigma_c = 0.66 \times 10^7$.

For the purpose of determining the resistive-wall impedance, we have re-assign the chamber-type into different cross-section and applied with different analytical formulas for the resistive wall impedance as:

- We apply the analytical formulas for round chamber with or without NEG coating to calculate the chambers includes: all the chambers in the arc with matching sections list in Tab. 1, as well as new ID chamber and other part in straight section as list in Table 2.

The analytical formulas for resistive wall impedance in unit length of the round chamber with NEG coating is [4]:

$$Z_{\parallel}(\omega) = \frac{Z_0 \omega}{4\pi bc}\left([\mathrm{sgn}(\omega) - i]\delta_1 \frac{\alpha \tanh\left[\frac{1-i\mathrm{sgn}(\omega)}{\delta_1}\Delta\right] + 1}{\alpha + \tanh\left[\frac{1-i\mathrm{sgn}(\omega)}{\delta_1}\Delta\right]}\right),$$

$$Z_{\perp}(\omega) = \frac{Z_0}{2\pi b^3}[1 - i\mathrm{sgn}(\omega)]\delta_1 \frac{\alpha \tanh\left[\frac{1-i\mathrm{sgn}(\omega)}{\delta_1}\Delta\right] + 1}{\alpha + \tanh\left[\frac{1-i\mathrm{sgn}(\omega)}{\delta_1}\Delta\right]},$$

with δ_1 the skin depth of the coating, $\delta_1 = \sqrt{\frac{2}{\mu_0 \sigma_{c,1}|\omega|}}$, Δ the coating thickness, and, for a good conductor $\alpha = \delta_1/\delta_2$, with δ_2 the skin depth of the substrate, which is suppose to be of infinite thickness. When we take $\Delta = 0$ in the formulas, it goes back to the classical resistive wall impedance formulas [5].

- The RW impedance of chambers with elliptical cross-section, as well as the plate chamber are obtained from that of a round chamber with radius equal to the minor semi axis of the ellipse by applying certain dimensionless factors, known as Yokoya's factors, depending on the ellipse aspect ratio. This is applied to: the supperbend chamber in the arc section, as well as the EUP, wiggler, keyhole, ellipse-1, ellipse-2 chamber, and the section with the most narrow vertical gap in the ring, which includes:the kicker and LEDA chamber as list in Table 2.

The Yokoya's factor [6] is given as a function of the elliptic parameter q with: $q = \frac{a-b}{a+b}$. For most of the SR chamber with large dimension in x (a) and small dimension in y (b), $q > 0.5$, that corresponding to the Yokoya's factor in longitudinal direction is $F_z = 0.98$, and factor of dipolar components in x direction $F_{d,x} = 0.43$, factor of dipolar components in y direction $F_{d,y} = 0.83$, and the quadruple components factor is $F_q = 0.4$, which is defocusing in Y direction and focusing in X direction.

- Noticed that we have do some approximation for the vacuum chamber without regular cross-section as the arc-keyhole, antechamber and elliptical-keyhole in the straight section.

We calculate the longitudinal and transverse dipolar resistive wall impedance for the ALS-U chamber, which is 12 total normal arc sections list in Tab. 1, with Yokoya's factor modification from round chamber into the ellipse dipole chamber, and the formulas for the plate chambers, results are shown in Fig. 3.

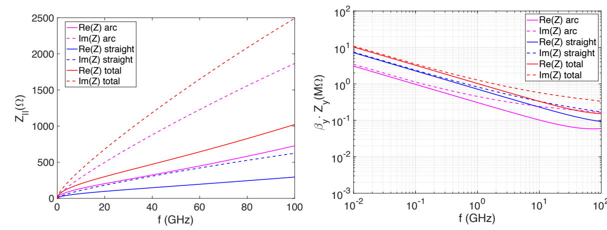

Figure 3: Longitudinal and vertical impedance of resistive wall.

GEOMETRIC IMPEDANCE

The geometric impedance is calculated with CST, which depends on the detailed cross-sectional variation of various components along the vacuum vessel, as flange, BPM, gate valve and so on shown in Fig. 4. Besides, the arc-keyhole chamber with longitudinal asymmetry is also a source of geometry impedance in the ring.

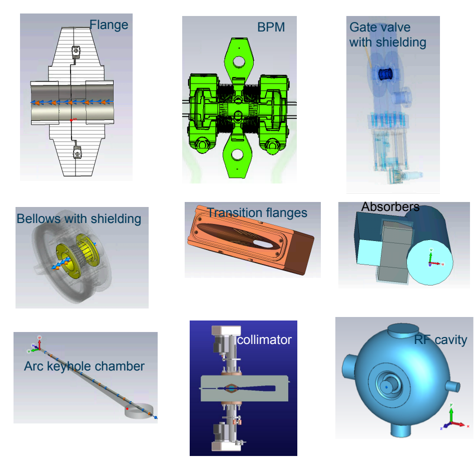

Figure 4: Examples of the geometric impedance source in the SR.

Majority of the geometric impedance components in the ring has been studied via 3D particle studio in CST. As Table 3 list various geometric components together with resistive wall that contribute to the total impedance model.

SHORT-RANGE WAKEFIELD BUDGET

The short range wakefield from components and sum are show in Figs. 5 (longitudinal) and 6 (vertical). As the FWHM bunch length of the storage ring is 34 mm with high-order harmonic cavity (HHC) to stretch the bunch length to a flat-top beam, and the flat-top beam has a similar frequency spectrum with a Gaussian beam with rms bunch

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Table 3: SR: associated key parameters of broadband impedance (longitudinal and transverse) for the relevant sources in the SR. Calculation of factor for 14-mm-rms-long bunch.

		Single					Sum				
Component	**Quantity**	κ_z V/pC	**Re(Z$_z$/n) mΩ**	**Im(Z$_z$/n) mΩ**	κ_x **V/pC/m**	κ_y **V/pC/m**	κ_z **V/pC**	**Re(Z$_z$/n) mΩ**	**Im(Z$_z$/n) mΩ**	$\Delta\nu_x$ $\times 10^{-4}$	$\Delta\nu_y$ $\times 10^{-4}$
RW	1	-0.481	38.304	90.037	1063.570	2090.861	-0.481	38.304	90.037	1.703	3.827
collimator	2	-0.000	-0.121	19.680	426.245	426.245	-0.000	-0.243	39.360	0.683	1.560
flange	384	-0.000	-0.012	0.198	1.243	1.243	-0.002	-4.542	76.103	0.486	0.988
transitions*[1]	10	-0.045	3.566	3.422	9.030	47.985	-0.448	35.660	34.218	0.145	0.878
gate valve	48	-0.000	0.009	0.519	3.869	3.869	-0.000	0.449	24.900	0.334	0.704
BPM*[2]	216	0.000	-0.017	0.092	0.622	0.622	0.046	-3.689	19.841	0.072	0.270
arc-keyhole	12	-0.038	2.572	5.987	44.373	6.299	-0.459	30.868	71.840	0.731	0.173
HHC	1	-0.511	40.683	-21.783	5.812	5.812	-0.511	40.683	-21.783	0.028	0.032
absorber	50	-0.008	0.617	1.437	38.918	0.441	-0.388	30.868	71.840	0.890	0.017
LFB	1	-0.262	20.861	-15.069	5.946	5.946	-0.262	20.861	-15.069	0.010	0.011
RF cavity	2	-0.600	47.788	-31.877	0.000	0.000	-1.200	95.575	-63.754	0.000	0.000
Ring total							-3.703	284.795	327.533	5.081	8.460

length 14 mm, thus we usually chose a drive bunch of rms bunch length 14 mm in CST simulations to get the impedance budget. For the transverse impedance, we mainly concern the vertical plane, which has more severe impedance issue, rather than the horizontal plane, mainly because the vertical impedance is much larger due to the narrow gap in this plane such as the LEDA type in vacuum undulators, and the beta function in the vertical plane is larger.

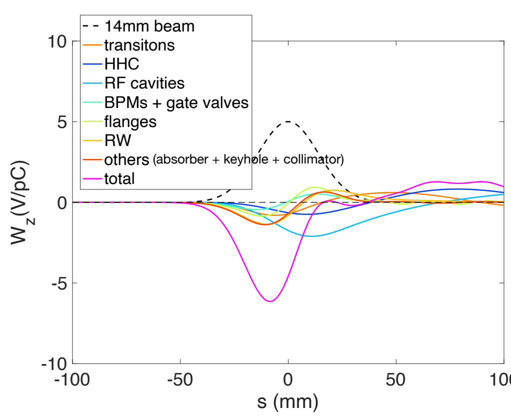

Figure 5: Longitudinal short range wakefield for various sources and their total (14 mm long rigid drive bunch).

Table 3 list the key impedance parameters for different sources in the SR, $\kappa_{\|}$ is the longitudinal loss factor. Z_z/n is the normalized impedance. κ_x and κ_y are the transverse kick factors. And the coherent tune shift is calculated as $\delta v = \frac{Q\beta\kappa_{\perp}}{4\pi E/e}$, where $Q = 1.15$ nC is the drive beam charge and $E \approx 2$ GeV is the average beam energy.

For the longitudinal budget, the largest contribution to the real part of normalized impedance (proportional to the loss factor) is from the RF cavities, and the largest contribution to the imaginary part of normalized impedance is from the resistive wall. For the vertical budget, RW is the largest source due to the narrow dimension of beam pipe, and the

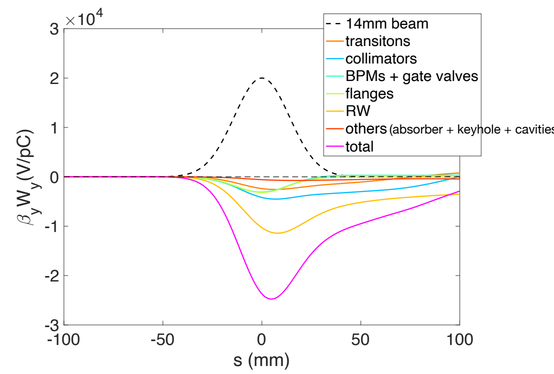

Figure 6: Beta-weighted vertical short range wakefield for various sources and their total (14 mm long rigid drive bunch).

collimators are the second largest sources, which guide us to work in progress of optimizing the new collimator design for impedance reduction.

CONCLUSION

In summary, we have presented the up-to-date broadband impedance budget for the ALS-U storage ring, with budget figures and tables show the contributions from different impedance sources along the ring, the results of our analysis are the basis for single bunch instability study, and would feedback on the design of critical vacuum components.

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