

DEVELOPMENT OF THE IMPEDANCE MODEL IN HEPS *

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Abstract

The High Energy Photon Source (HEPS) is a new designed photon source at beam energy of 6 GeV. Due to the small beam pipe aperture and a large number of insertion devices in the machine, the impedance can drive collective instabilities and limit the machine performance. Therefore, a thorough estimation of the coupling impedance is necessary in controlling the total impedance of the whole machine. A primary impedance model is obtained for the storage ring.

INTRODUCTION

The HEPS was proposed as a low emittance light source [1]. Two operational modes with different filling patterns are considered. One is high brightness mode with 648 bunches, followed by 10% of gap. The other one is the timing mode, with 60 bunches uniformly distributed in the ring. A novel on-axis longitudinal injection scheme based on two active RF systems was proposed [2]. The injection process will take 200 ms for each cycle. This scheme has a short bunch of 3 mm during the injection process, and the operational bunch length is about 3 cm long. The bunch will be lengthened by harmonic RF cavities after injection to release the collective effects and intra-beam scattering. The short bunch length during injection gives critical requirements on the impedance and the collective instability studies.

In this paper, the most recent impedance model developed for various components of the main ring is discussed. The impedance model with bunch length of 3.0 mm is constructed for collective instability studies.

IMPEDANCE CALCULATION

The impedance and wake are calculated with analytical formulas along with numerical simulations with ABCI [3] and CST [4]. The impedances and wakes are obtained with a bunch length of 3 mm. The vacuum components considered in this calculation includes resistive wall, RF cavities, bellows, flanges, tapers of the out-vacuum IDs, in-vacuum ID chambers, extraction kickers, BPMs, harmonic cavities, longitudinal and transverse feedback kickers. There are still some elements missing in the calculation. A more complete impedance model will be calculated as additional vacuum components are designed.

Resistive Wall

In HEPS, the beam pipes with antechamber are mainly adopted, which occupies about 40% in the total length of the ring. The beam pipes have half height of 11mm, and are mainly used for the bending magnets and for the pho-

ton extraction. The beam pipes with circular cross-section of 11 mm aperture occupies about 30%. Other parts of the ring will be occupied by the IDs, RF cavities, injection and extraction components, diagnostic components etc.

The main parameters of the vacuum chambers are listed in Table 1. The main vacuum chamber is made from stainless steel with 0.5 μm of copper coating on the inner surface to reduce the impedance. The stainless steel chamber without coating is used at the fast correctors. The copper vacuum chamber with NEG coating will be used at the multiple magnets and the out vacuum insertion devices. The thickness of NEG coating is around 1 μm . The vacuum chambers with 2.5mm aperture corresponds to the in vacuum insertion devices.

Table 1: Main Parameters of the Vacuum Chambers

Material	Aperture	Length
Stainless steel + Cu	11 mm	679 m
Stainless steel	11 mm	48 m
Cu + NEG	11 mm	277 m
Cu + NEG	5.5 mm	180 m
Ion + Ni + Cu	2.5 mm	30 m

To calculate the resistive wall impedance, the beam pipes are assumed to have a round shape. The analytical formulae of cylindrical multi-layer beam pipe with finite thickness are used in the calculation [5]. The longitudinal and transverse wake potential contributed from different vacuum chambers is shown in Fig. 1 and Fig. 2, respectively. The calculation gives total longitudinal effective impedance of 27 m Ω , which is dominated by the copper beam pipe with NEG coating. The total transverse kick factor is 12.4 V/pC/m, which is dominated by the vacuum chambers at the insertion devices due to the restricted beam pipe aperture.

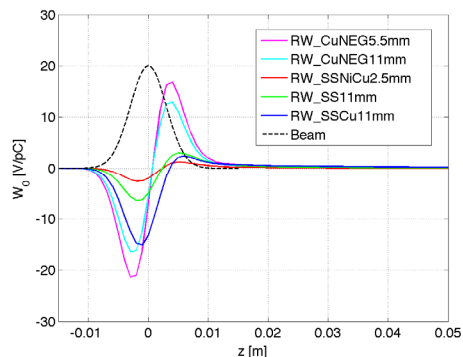


Figure 1: Longitudinal wake potential with bunch length of 3 mm contributed from different vacuum chambers.

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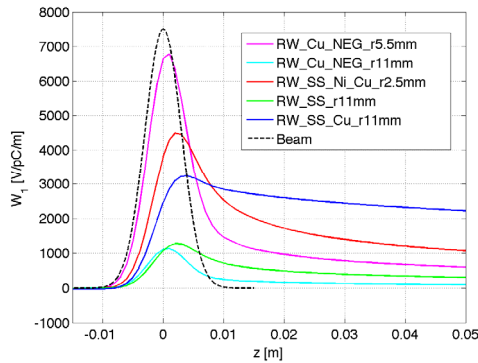


Figure 2: Transverse wake potential with bunch length of 3 mm contributed from different vacuum chambers.

RF Cavities

Superconducting RF cavities with monopole frequency of 166.6MHz are adopted in the main ring. Four RF cavities are needed in order to provide a maximum accelerating RF voltage of 3.5 MV. The impedance and wake are calculated with the code ABCI. The schematic view of the RF cavity used in the impedance calculation is shown in Fig. 3. By fitting the longitudinal wake potential at the nominal bunch length with the analytical model [6],

$$W(s) = -Rc\lambda(s) - Lc^2\lambda'(s). \quad (1)$$

we get the effective resistance of $R = 95 \Omega$, and inductance of $L = 0.4 \text{ nH}$. The calculated loss factor for one RF cavity is $k_l = 2.675 \text{ V/pC}$. The transverse kick factor normalized by the betatron function is $k_t = 27.9 \text{ V/pC/m}$.

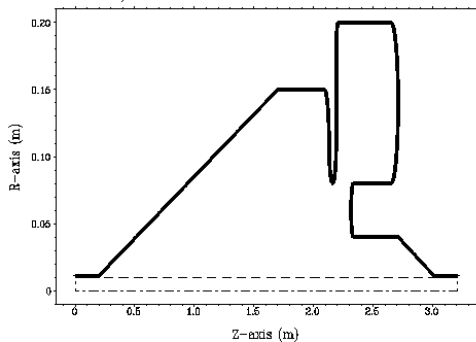


Figure 3: Schematic view of the RF cavity.

Flanges

The impedance of the flanges is mainly generated by the longitudinal slit between the two plates. In the primary study, the structure with shielding spring as shown in Fig. 4 is used in the calculation [7, 8]. The dimension of the longitudinal slit is largely reduced due to the shielding. The calculation shows that the effective longitudinal impedance for one flange is $0.026 \text{ m}\Omega$ and the transverse kick factor is 2.2 V/pC/m . However, since a large number of flanges will be installed in the ring, the total impedance contribution from the flanges is not trivial. A new design of flange with zero impedance is under investigation.

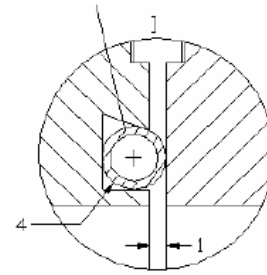


Figure 4: Geometrical model of the flange with shielding.

Bellows

In order to reduce the impedance of bellows, RF shielding fingers will be used. Impedance due to the taper of the sliding finger is the main contribution to the impedance of the structure. The longitudinal and transverse impedance are mainly broadband at low frequency up to 10 GHz. The impedances show resonances at high frequency above 10 GHz. The result gives a longitudinal effective impedance of $0.035 \text{ m}\Omega$ and transverse loss factor of 4.0 V/pC/m for one bellows. The impedance contribution to the total impedance is also not trivial due to the large quantity.

Extraction Kickers

The extraction kicker has a strip-line structure as shown in Fig. 5. The impedance spectrum shows resonances every $\sim 200\text{MHz}$. This is mainly determined by the resonant structure formed between the metal plates and the vacuum tank. The contribution to the broadband longitudinal impedance is small. The contribution to the transverse kick factor per kicker is 288.2 V/pC/m .

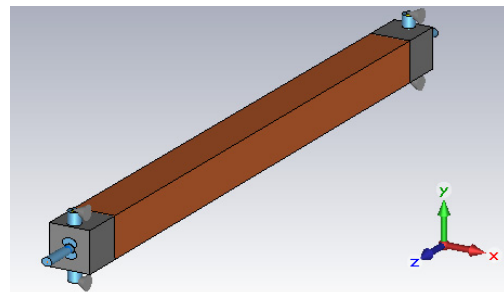


Figure 5: Geometrical model of the strip-line extraction kicker

The simulation gives total loss factor of 0.72 V/pC per kicker. The total power loss during injection is around 2 kW for the 60-bunch mode. The heat load dissipation in the structure is studied numerically. The total power lost on the metal plates and the vacuum tank is 233 W and 288 W, respectively. About 838 W and 625 W of power loss will transport to the upstream and downstream feed-throughs. However, since the 3 mm bunch length only exist during injection, which takes about 200 ms in one cycle of 2 minutes, the power can be largely reduced when we consider the average power loss during one cycle.

Feedback Kickers

Longitudinal and transverse feedback kickers will be used to damp the collective instabilities. For the longitudinal feedback system, a cavity shape kicker will be used. The contribution of the kicker to the longitudinal impedance is 0.7 m Ω , and the contribution to the transverse kicker factor is 40.7 V/pC/m. The impedance shows resonances at low frequencies. The influence of these modes to the beam instability is under study.

A stripline kicker will be used for the transverse feedback system. The impedance is mainly broadband, except resonances of small amplitude above 8GHz, which are far below the coupled bunch instability threshold. The contribution of the kicker to the longitudinal impedance is 0.2 m Ω , and the contribution to the transverse kicker factor is 31.3 V/pC/m. The contributions of both longitudinal and transverse feedback kickers to the total broadband impedance are small.

In-vacuum ID Chambers

The geometrical model of the in-vacuum ID chamber is shown in Fig. 6. The whole structure including the sliding finger and the vacuum tank is modelled in the simulation. Two operational situations with jaws open (gap = 5 mm) and closed (gap = 40 mm) are considered, respectively. The impedance is mainly broadband. The contribution to the longitudinal impedance is 0.2 m Ω when the jaws are closed, and 1.0 m Ω when the jaws are open. The contribution to the transverse kick factor is 187.0 V/pC/m with jaws closed and 20.0 V/pC/m with jaws open.

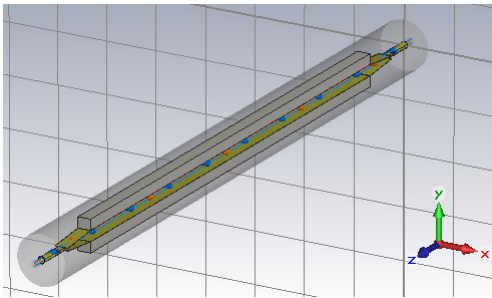


Figure 6: Geometrical model of the in-vacuum ID chamber used in the simulation (with jaws open).

Taper Transitions of the Out-vacuum IDs

For the out-vacuum insertion devices, transition tapers will be used to transfer from an aperture of 5.5 mm to 11 mm. The impedances for taper-in and taper-out transitions are calculated separately. The impedances are mainly broadband in both longitudinal and transverse planes. By fitting the longitudinal wake potential with the analytical model, we get effective inductance of 0.1nH for one pair of tapers, which corresponds to longitudinal effective impedance of 0.15 m Ω . The transverse kick factor is 26.4 V/pC/m.

BPMs

Four button BPM will be used in the HEPS main ring. The longitudinal and transverse impedance are calculated

with a bunch length of 3 mm. Calculations show longitudinal broadband impedance of 0.036 m Ω and transverse kick factor of 4.6 V/pC/m for one BPM. The broadband impedance contribution of all BPMs is high since a large number of BPMs will be used in the ring. The simulations also show high resonances around 15 GHz. More detailed analysis of the power loss dissipation and further impedance optimization are needed.

Harmonic Cavities

Harmonic cavities are used in order to lengthen the bunch and also serve for the on-axis longitudinal injection. There are two superconducting RF cavities with fundamental frequency of 500 MHz serve for this purpose. The two cavities will be located in one long straight section. The longitudinal broadband impedance of the whole harmonic RF system is about 1.1 m Ω , and the transverse kick factor is 64.0 V/pC/m.

SUMMARY

The contribution from resistive wall and geometrical impedance are summarized in Table 2. The calculation gives total longitudinal effective impedance of 0.11 Ω , which is mainly contributed by the resistive wall impedance and the elements with large quantity. The total longitudinal loss factor is 85 V/pC/m, and the corresponding total HOM power during injection is around 23 kW with 648 bunches and 246 kW with 60 bunches. The values will be largely reduced when consider the bunch lengthening due to longitudinal impedance. The total transverse kick factor is 24 kV/pC/m. The transverse impedance is dominated by the resistive wall impedance.

Table 2: Summary Table of the Impedance Budget

Objects	$Z_{ /n}$ [m Ω]	k_y [V/pC/m]
Resistive wall	27.0	12.4
RF cavities	2.3	0.1
Bellows	13.8	1.6
Flanges	26.3	2.2
ID Tapers	9.1	1.6
Ext. kickers	0.09	1.2
BPMs	27.4	3.5
Harmonic RF	1.1	0.06
Long feedback	0.7	0.04
Trans feedback	0.2	0.03
In-vacuum IDs	1.0	0.9
Total	109.0	23.6

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