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IMPEDANCE MEASUREMENTS OF KEY ELEMENTS IN THE HEPS

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Abstract

Impedance modelling is an important subject in diffraction limited storage rings based light sources, due to the adopted small beam pipe as well as the tight requirements from beam collective effects. However, for the complex elements such as the in vacuum undulators or kickers, it can be hard to be modelled in the simulations without simplification of the model. Therefore, a batch of impedance bench measurements are performed or planned for the dominant impedance contributors in HEPS, including resistive wall impedance of the NEG coated vacuum chambers, as well as the geometrical impedance of components with large impedance for single element or that show large contributions due to large quantities. In this paper, the impedance measurement of the key elements in the HEPS will be discussed, and the main results are given and compared with the theoretical estimations.

INTRODUCTION

The High Energy Photon Source (HEPS) [1] is designed with beam energy of 6 GeV and natural emittance of less than 60 pm. The typical vacuum chamber has a circular cross section with radius of 11 mm. The vacuum chambers are made of copper (CuCrZr) with a layer of 1μm NEG coating on its inner surface. There are also antechambers at the location of the bending magnets. The antechambers are made of stainless steel with a layer of ~20μm copper coating on its inner surface to reduce the resistive wall impedance. The full aperture at the undulators is around 5~8 mm.

Considering the beam collective instabilities, due to the small momentum compaction factor, the impedance can have an influence on the stationary beam parameters [2], as well as restrict the single bunch intensity [3, 4]. Meanwhile, the impedance induced transient effect during injection can also become potential restrictions to the ring injection. To mitigate these effects, harmonic RF cavities as well as positive chromaticity are adopted [3, 4]. Considering the above situations, the impedance needs to be carefully modelled and well controlled.

According to the careful modelling of the ring impedance [3, 5], the dominant impedance contributors in HEPS are identified, which includes the resistive wall impedance, as well as the geometrical impedance of components with large impedance for single elements, such as the injection stripline kickers, and the in-vacuum undulators, or that show large contributions due to large quantities, such as the BPM and bellows assemblies.

However, for the complex elements such as the in vacuum undulators or kickers, it can be hard to be modelled in the simulations without simplification of the model. Impedance bench measurements can be very useful tools to verify the validity of the impedance model, as well as to find any missing impedance sources.

In this paper, the impedance bench measurements for the key vacuum components, including resistive wall, injection stripline kicker, in vacuum undulators, RF cavities, BPM and bellows assembly, as well as flanges, are discussed. There are also measurement plans for other components, such as collimators, dump kickers, and feedback kickers, which will not be covered in this paper.

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RESISTIVE WALL

The resistive wall impedance, due to the finite conductivity of the beam pipe, is one of the major contributions to the beam coupling impedance. Since NEG coating is widely adopted for the vacuum pumping in the limited vacuum chamber. Therefore, the resistive wall impedance of the NEG coated chamber is measured with both the resonant line method and resonant cavity to identify the electrical conductivity of NEG at high frequency.

The resistive wall impedance measured is compared with the analytical estimations as shown in Fig. 1. Here, the conductivity of NEG and CuCrZr measured by the resonant cavity at frequency of ~13 GHz has been used, with values of 0.4 MS/m and 32 MS/m, respectively. In the theoretical estimation, the thickness of NEG coating is assumed to be 1 μm. The measured impedance of the NEG coated chamber shows good agreement with the theoretical estimation below 5 GHz. However, above this frequency, the measured impedance is higher than the theoretical estimations and show unexpected resonances. The higher impedance compared to the theoretical estimation can be introduced by the influence of the surface roughness at higher frequencies or larger thickness of NEG.

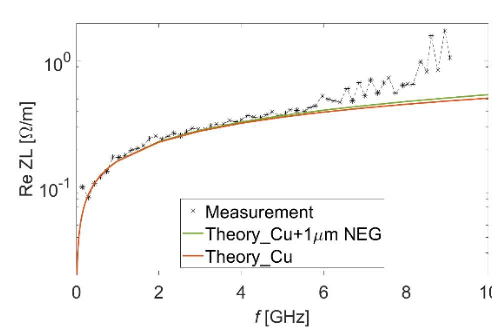

Figure 1: The real part of the resistive wall impedance of the NEG coated CuCrZr beam pipe given by the resonant line measurement, which is compared with the theoretical estimations with and without NEG coating.

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In addition, to evaluate the impedance of the stainless chamber with copper coating, the conductivity of a batch of copper coating samples at high frequency is measured with the same resonant cavity setup at ~13 GHz as used in the measurement of NEG coating [6]. The results indicate that when the skin depth of copper is comparable to or larger than its surface roughness, its effective conductivity will be significantly reduced, as shown in Fig. 2. Therefore, the roughness of the copper coating chambers should be well controlled, in order to control its impedance contributions.

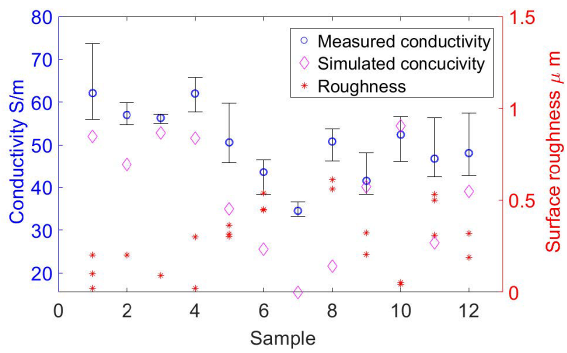


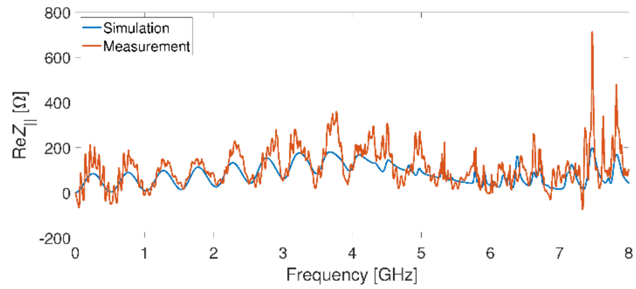
Figure 2: Conductivity and surface roughness measured for different copper coating samples. The simulated conductivity is the one calculated by CST [7] macros with the input of the DC conductivity and the surface roughness measured.

INJECTION STRIPLINE KICKER

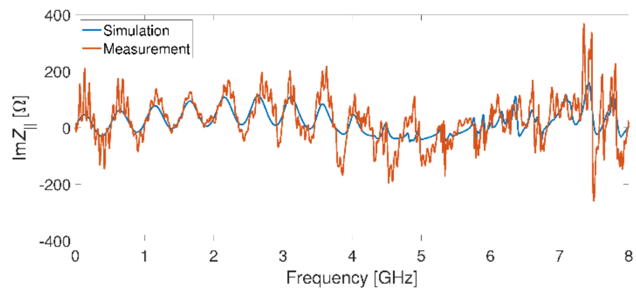
The beam coupling impedances of the stripline kickers show large contributions to the total impedance budget. In HEPS, the necessity of the short pulse bottom width (less than 10 ns) and strong deflection field requires the kicker to have a short length and a small gap between the electrodes, respectively. A novel five-cell stripline kicker is proposed in order to save longitudinal space as well as to reduce the beam coupling impedance. Comprehensive studies have been undertaken to characterize the impedance of the stripline kicker, and a batch of impedance bench measurements based on coaxial wire method are launched to identify the impedance experimentally [8]. A satisfactory agreement has been reached between the numerical predictions and the measurements, as shown in Fig.3.

The results show that both the longitudinal and transverse impedances of the five-cell stripline kicker present TEM-mode-like resonances below ~ 4GHz. In this frequency range, the impedance behaviour is more or less identical to that of the single cell kickers, since the electromagnetic field generated by the beam is more localized. However, at frequencies above 4 GHz, the impedances are remarkably reduced in comparison to five, individual, single cell kickers, due to the mitigation of the resonant effect from the interaction among different kicker cells.

In addition, in order to hold and stretch the conducting wire at the center of the small beam pipe, a novel fasten block design with ceramic is proposed and tested, as shown in Fig. 4. This can be quite useful for the coaxial wire measurements of rather long structures with small apertures.



(a)



(b)

Figure 3: The real part (a) and imaginary part (b) of the longitudinal impedance measured by the coaxial method, and compared with simulations.

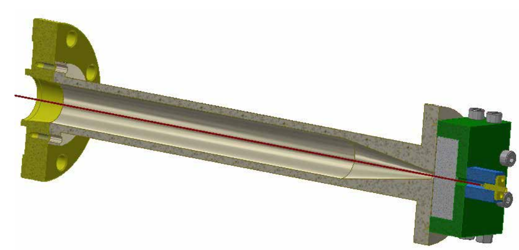


Figure 4: The CAD drawing of the matching section and mounting of the wire with the ceramic fasten block.

IN VACUUM UNDULATORS

The in vacuum undulators show both large contributions to the broadband impedance and vertical high order modes (HOMs) due to the ridge waveguide structure formed by the magnetic poles and the vacuum chamber tank. The schematic view of the transverse cross section at the center of the IVU is shown in Fig.5. The longitudinal impedance is measured by the coaxial wire method. At the natural bunch length of 22.9mm with harmonic RF cavity, the longitudinal effective impedance calculated with the measured impedance is approximately 60% higher than the simulation results. It also observed that the shape of the RF finger for the transition between the magnetic pole and the beam pipe shows large influence on the broadband impedance.

In addition, the transverse HOMs are measured with the coupling probes. The key parameters of the first four dominant HOMs are listed in Table 1, and compared with the

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simulation results. The measured frequencies of the modes show good agreement with the simulations. However, the quality factors measured are much lower than the simulations. This can be explained by the damping effect of the complex components of the structure. The results are similar to that studied at SPEAR3 [9]. With the measured quality factors, the shunt impedance of the HOMs are evaluated, which shows that at resonant condition, the impedance is still higher than the impedance threshold given by the synchrotron radiation damping and bunch-by-bunch feedback system is needed.

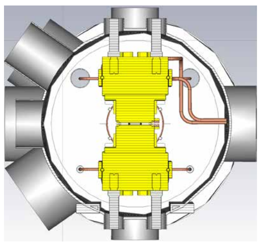

Figure 5: Transverse cross section view at the center of the IVU.

Table 1: Comparison of Measurement and Simulations on the IVU HOM Parameters

Simulation		Measurement	
f [MHz]	*Q*	*f* [MHz]	*Q*
74.1	2483	75.9	153
87.8	1875	88.9	268
109.6	1531	110	241
136.7	1416	136.4	329

BPM AND BELLOWS ASSEMBLY

In order to mechanically isolate the BPMs from vacuum chamber vibrations and to accommodate chamber expansions, compact BPM-bellows assemblies are commonly used in HEPS. Although the impedance contributed by a single element is small, considering their large quantity, their total contribution to the broadband impedance of the ring is large. In addition, narrow band impedances are observed around the cut-off frequency of the vacuum chamber according to the simulations.

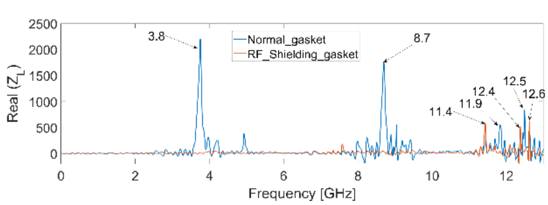

Figure 6: Real part of the longitudinal impedance of five BPM and bellows assemblies connected with flange gaskets with and without RF shielding.

During the measurements, considering the low impedance amplitude for single element, five BPM and bellows assemblies are connected either with four flange gaskets with RF shielding or normal gaskets without RF shielding. Therefore, the efficiency of the RF shielding can be identified from the measurements. The measured results are shown in Fig. 6. By comparing the impedance with the flange gasket with and without RF shielding, the contributor for the resonances can be confirmed. The resonance at frequencies of 11.4 GHz and 12.6 GHz are contributed by the BPM and bellows assembly, while at frequency of 12.4 GHz is contributed by the flange gasket with RF shielding, which is not expected from simulations. This can be contributed by the mounting errors or corrupted RF fingers. In the contrast, the resonances at 3.8 GHz, 8.7 GHz, 11.9 GHz and 12.5 GHz are generated by the cavity structure formed by the normal gasket, which is then further conformed by the simulations.

RF CAVITIES

The RF cavities show large contributions to the ring total loss factor. Therefore, the impedance of the TF-POP RF cavity [10] was measured with coaxial wire method. The impedance is shown in Fig. 7 and compared with simulation results. The impedance shows rich of resonances. The first two dominant HOMs show good agreements with the simulations. The loss factor obtained from measurement is approximately 1.5 times lower than the simulations.

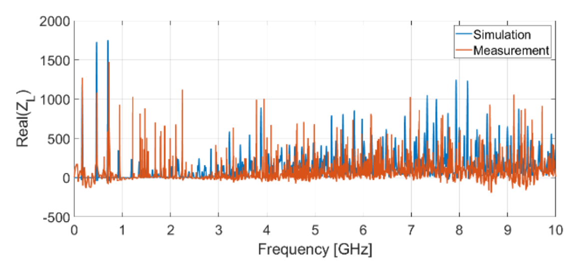

Figure 7: Real part of the longitudinal impedance of POP type RF cavity and compared with wakefield simulations.

SUMMARY

The impedance bench measurement for the key vacuum components, including resistive wall, injection stripline kicker, in vacuum undulators, RF cavities, BPM and bellows assembly, as well as flanges, are performed. The results identified several impedance issues and provide us with a better understanding of the impedance contributions. However, there still exist some discrepancies between the measurements and simulations. The reasons for these discrepancies should be further identified.

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