IMPEDANCE ESTIMATION OF DIAMOND CAVITIES

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Abstract

The RF straight section of the Diamond storage ring presently consists of two CESR type SCRF cavities with a provision to install a third cavity in future. The cavities are equipped with HOM loads on the beam tubes which are joined to the adjacent storage ring beam pipe using tapered transitions. The RF cavities and the tapers are simulated with MAFIA, CST Studio and ABCI to estimate their contribution to the total ring impedance. In this paper we present the results of our measurements and simulations which lead us to an estimation of the impedance of the RF straight.

INTRODUCTION

The CESR type SCRF cavities use beam pipes with a large radius (ϕ240 mm) in order to reduce the cutoff frequencies of Higher Order Modes (HOMs). This enables these modes to propagate into the beam pipe where they are damped by HOM loads. Additionally, the beam pipe cross-section on one side of the cavity is 'fluted' to further enhance the propagation of the lowest order dipole modes to the HOM load. To minimise the contribution of the RF straight to the overall ring impedance, the beam pipe in the RF straight is matched to the narrower beam pipe in the adjacent straight section with tapered transitions. As the length of the RF straight is 8.3 m, individual components of the rf straight are simulated in 2D or 3D depending on whether the components are cylindrically symmetric or not. A check is performed on the estimates by comparing the 2D results from two different codes MAFIA [1] and ABCI [2]. The natural rms bunch length (σ_l) in Diamond is ~3 mm. From a simulation consideration, this forces the selection of mesh sizes $\Delta x = \Delta y = \Delta z$ to less than 1 mm to provide realistic numerical estimates. The mesh size used in all of the 2D simulations is 0.25 mm. For 3D studies, we have used CST Particle Studio with mesh size < 1mm. The taper angle (α) for both the tapers is 11.3°. In addition to the cavities, the RF straight also consists of other essential components including gate valves, pumping ports, bellows, etc. These components are equipped with RF finger strips / contacts with minimal protrusion into the beam pipe, minimising their contribution to the total impedance. Simulation results of the large gate valve and the flanges show their contribution to be negligible. Figure 1 shows a single cavity with tapers on both ends. The RF straight actually consists of two adjacent installed cavities connected via a ϕ240 mm pipe and an additional long full diameter pipe in place of the space reserved for 3rd cavity. This is connected between cavity 2 and the beam exit taper.

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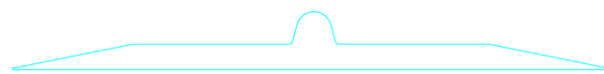

Figure 1: Simplified geometry of a cavity with beam pipes and tapers on both ends as simulated by MAFIA and ABCI.

IMPEDANCE COMPUTATIONS IN 2D

To estimate the impedance and to establish the applicability of the composition rule, the cavity is simulated with extended beam tubes and tapers on both sides. The simulations were carried out in 2D using MAFIA and ABCI. The beam tube and tapers, but excluding the cavity, are simulated separately, as are the individual tapers. In all these simulations the mesh size in radial and longitudinal directions is kept at 0.25 mm.

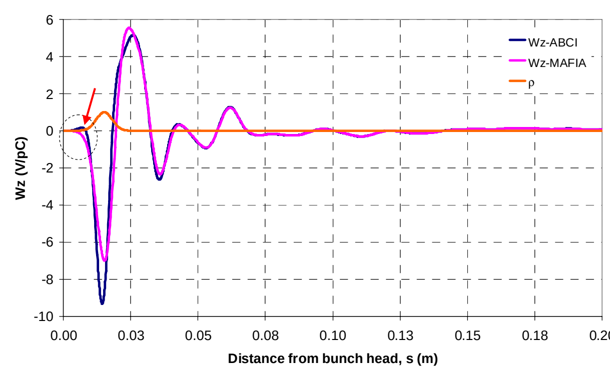

Figure 2: Longitudinal wake potentials computed by MAFIA (pink) and ABCI (blue) for the structure shown in Figure 1. Normalised charge density is shown by the orange curve.

Figure 2 shows longitudinal wake potentials computed in 2D by MAFIA and ABCI for the full cavity structure shown in Figure 1. Here short range wake potential values from ABCI do not agree well with those from MAFIA. In both cases wakefield integration is performed using the indirect method. It is observed that MAFIA results converge faster with mesh refinement compared to those from ABCI. Also the ABCI result has an unphysical wake (numerical noise) before the bunch highlighted by the red arrow. This unphysical wake did not disappear by reducing the mesh size further. Therefore, MAFIA results seem to be more realistic and acceptable for this structure. The real and imaginary parts of longitudinal impedance computed from wake potential values from ABCI and MAFIA are shown in Figure 3. At higher frequencies, the impedance computed by MAFIA (dark blue) shows a drastic disagreement with that from ABCI (pink) due to the inaccurate short range wake potential computed by ABCI. To estimate the contribution of individual components, the taper section without the cavity, the cavity alone and the individual taper sections are simulated separately.

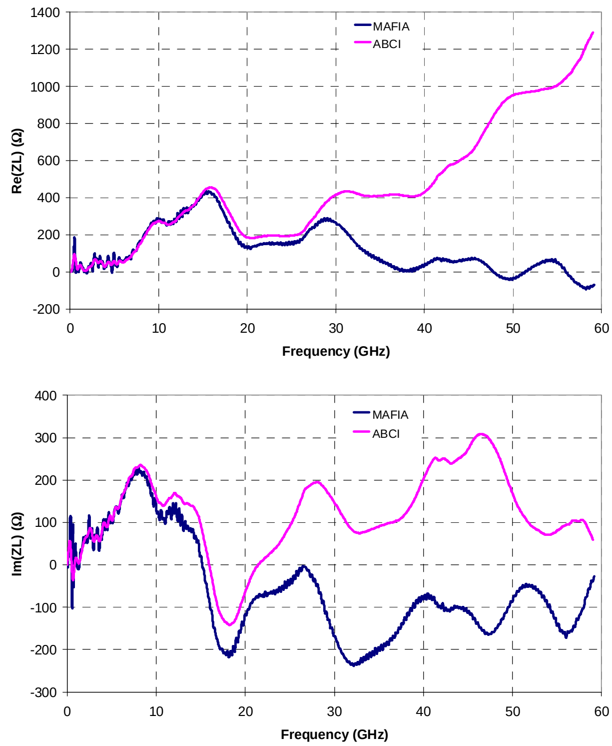

Figure 3: Real (top) and imaginary (bottom) parts of longitudinal impedance computed from wake potentials given by ABCI and MAFIA for structure shown in Fig. 1.

The real and imaginary parts of the impedance are shown in Figure 4 as computed from the wake potential given by MAFIA for the ϕ240 mm beam pipe in the RF straight with tapers on both sides. This is the same geometry as shown in Figure 1 without the cavity.

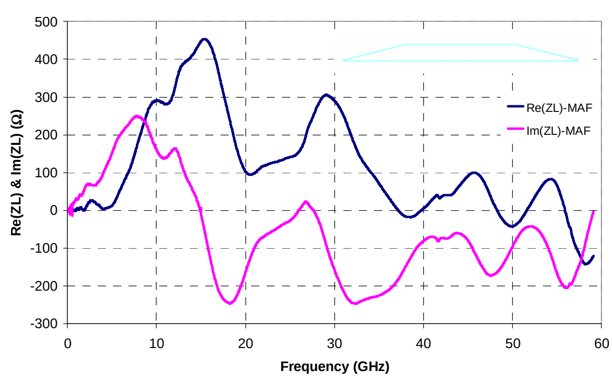

Figure 4: Real and imaginary parts of impedance for the symmetric cavity formed by two tapers as shown in the top right corner.

Comparing Figures 3 and 4, it can be seen that the major impedance contribution is from the tapers. The impedance of the cavity alone without tapers is shown in Figure 5. From Figures 3, 4 and 5, it can be seen that the impedance of the complete cavity structure with tapers (Figure 1) can be obtained by adding the impedance of the tapers (Figure 4) and the cavity (Figure 5) alone. The tapers (taper-in and taper-out) are simulated individually to verify the applicability of the composition rule. ABCI can compute the wake potentials for single tapers after correcting for the 'Log term' arising due to the difference in potential energies of the electromagnetic fields of the particle in beam pipes of different radii [2,3]. The wake potential for taper-in computed by MAFIA after correction for the log term is in good agreement with that computed by ABCI as shown in Figure 6. Dark blue and pink curves show wakes calculated by MAFIA before and after correction respectively. The light blue curve shows that computed by ABCI.

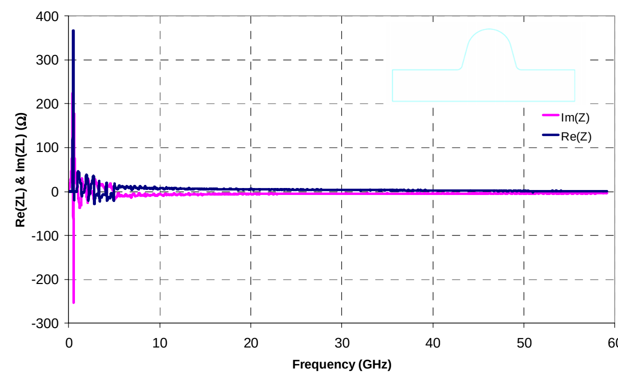

Figure 5: Impedance of the bare cavity without the tapers (shown in top right corner).

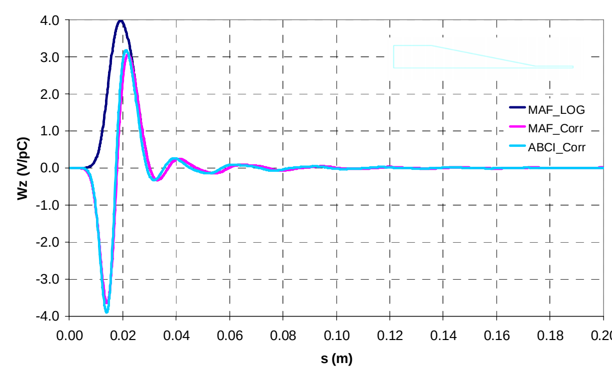

Figure 6: Wake potential computed for taper-in by MAFIA compared with that from ABCI after correcting for the 'Log' term.

IMPEDANCE COMPUTATIONS IN 3D

The long tapers deviate from cylindrical symmetry only in a small region near the junction to the non-circular cross-section of the straight section vacuum chamber. The fluted beam pipe on one side of the cavity is another such non-axisymmetric component. The simulation assumes cylindrical symmetry and gives a reasonable estimate of the impedance of these components. However to confirm this, these components are simulated individually in 3D to estimate their contribution to the total impedance. We used CST Particle Studio [4] for the simulations of 3D structures. Impedance results from CST Studio for the cavity structure with flutes and the flutes alone are shown in Figure 7. The wake potential is computed using the indirect method in both the cases. The sharp peaks (in the dark blue and pink curves) for the cavity with flutes are due to 500 MHz resonance of the cavity shell. It can be seen that the impedance contribution from the flutes alone is quite small compared to that of the cavity and the tapers considered earlier.

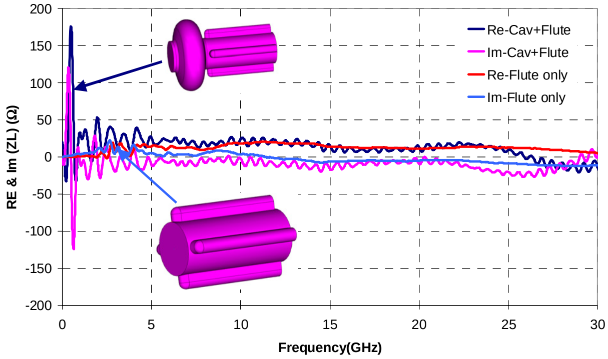

Figure 7: Impedance of cavity with flutes on (dark blue and pink) and flute alone (red and light blue curves) computed by CST Particle Studio.

SUMMARY

Wake potentials and impedances for individual components in the RF straight have been computed. MAFIA results provide a better estimate than ABCI as the ABCI results suffer from numerical noise in certain cases even with indirect integration method. Simulations with a yet more refined mesh are foreseen to estimate the contributions from 3D structures.

Table 1 lists the estimated loss factors for individual components in the RF straight. As expected the major contribution comes from the two tapers at both ends of the RF straight. The loss factor for the cavity shell alone computed in 2D is 0.33 V/pC and compared to 0.24 V/pC from the 3D simulations. Simulations with a finer mesh should reduce this difference. An upper estimate of the total loss factor of the RF straight assuming 2 or 3 installed cavities with flutes and two tapers is ~4.74 V/pC and ~5.3 V/pC respectively.

Table 1: Summary of loss factors

	Component	$k_{\|\|}$ (V/pC)	Comment
1	Cavity+beam tubes+tapers on both sides	4.433	2D
2	Beam tube + tapers on both sides	4.34	2D
3	Cavity alone	0.33	2D
4	Cavity estimated from (1) & (2)	0.1	2D
5	Cavity + flutes	0.568	3D
6	Flute alone	0.329	3D
7	Cavity estimated from (4) & (5)	0.239	3D
8	Taper-out	1.86	2D
9	Taper-in	1.74	2D

REFERENCES

[1] MAFIA, CST GmbH, Darmstadt, Germany.
[2] Y. H. Chin; User's Guide for ABCI Version 9.4, KE Report 2005-06.
[3] B. W. Zotter, S. A. Kheifets; Impedances and Wakes in High-Energy Particle Accelerators; World Scientific (1997) 351.
[4] CST Studio, CST GmbH, Dmarstadt, Germany.