Broad Band Waveguide to Coaxial Transition for HOM Suppression in RF Cavities for Future Synchrotron Light Sources

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Abstract

In the modern storage ring light sources, exploiting multi-bunch beams, the longitudinal and transverse coupled bunch instabilities are predominantly driven by higher order modes (HOM) of the accelerator RF cavities. In order to suppress the HOM to a harmless level, we propose using a modified broadband waveguide to coaxial line transitions placed on the cavity body, similar to those used for the DAΦNE collider RF cavities. Such a solution has a simple design that avoids the application of the ferrite materials under the ultra-high vacuum and dissipates the HOM power on the external loadings. Different from DAΦNE with a single cavity per ring, where the damping waveguides are placed laterally on the cavity body, we consider the possibility of allocating the waveguides vertically. Since the modern synchrotron light sources require using more RF cavities to compensate for the synchrotron radiation losses, such a solution helps to save the occupied space when placing the cavities in a row next to each other.

Introduction

In storage rings with multi-bunch circulating beams, coupled-bunch longitudinal instabilities can be induced by the interaction of the particle beams with the parasitic wakefields generated by the particle beam itself in the resonant RF cavities. The presented solution to eliminate these instabilities consists of coupling the HOMs out of the cavity over a reasonably wide frequency band employing waveguides (WG) connected to the cavity structure and dissipating the associated energy by the external loads.

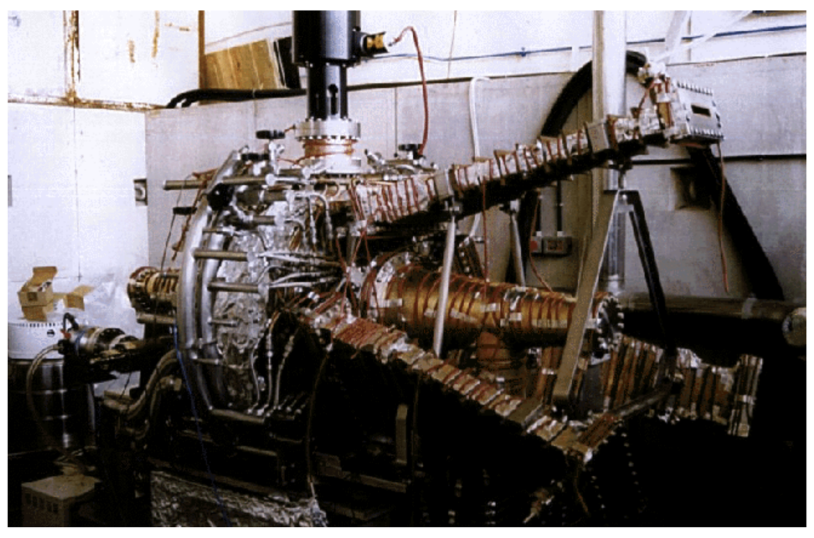


Figure 1: DAΦNE cavity prototype equipped with the HOM damping waveguides. [1, 2, 3]

This method has been demonstrated to reduce the HOM quality factors and shunt impedances by several orders of magnitude, reducing the intensity and decay time of the generated wakefields in the cavity.

A nosecone cavity design was used for the studies, typical for the operating synchrotron light sources. The fundamental frequency and cavity dimensions were chosen to be 357 MHz, [4].

WG to Coaxial Transition Line Structure

The dimensions of the rectangular part of the HOM suppression WG were chosen to have a cut-off frequency between the fundamental mode and second monopole mode frequencies. As the rectangular cross-section part of the WG is smoothly transferred to the linearly tapered one, the ridge of increasing height is also introduced to keep the cut-off frequency consistent. In the end, a transition to coaxial is constructed, Fig.2.

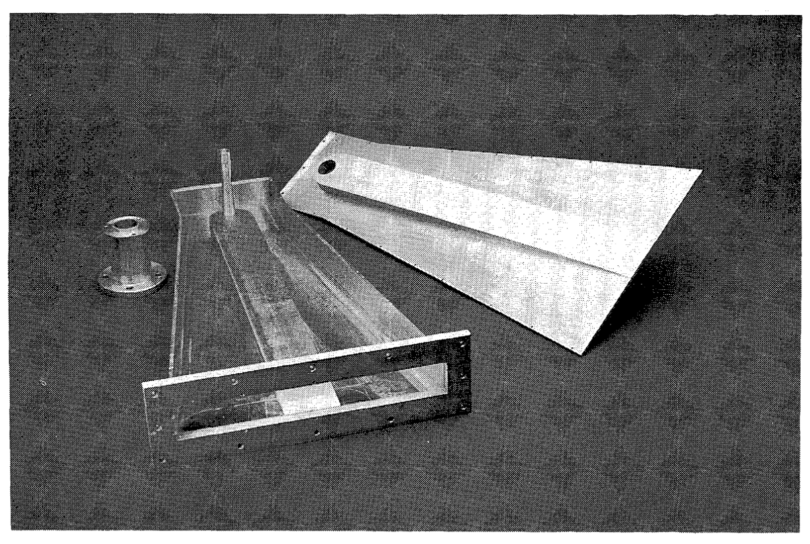
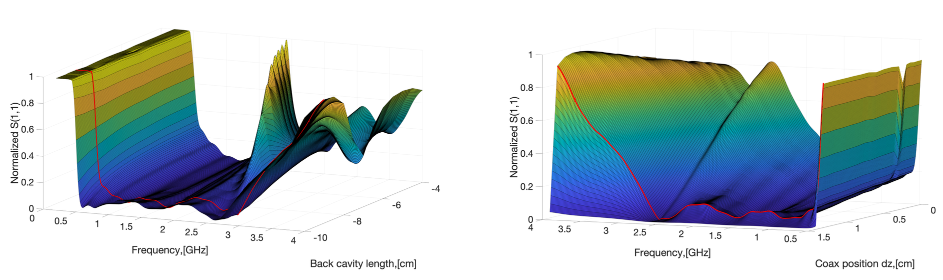


Figure 2: Dissembled tapered part of the damping waveguides of DAΦNE cavity. [3] Courtesy of A. Gallo.

WG to Coaxial Transition Line Optimisation process

Ridged WGs are more convenient than rectangular WGs for converting the fundamental TE_{10} WG mode to the coaxial TEM mode in a wide frequency band. Therefore, the waveguide-to-coaxial transition consists of two sections: a tapered transition from rectangular to double-ridged WG followed by a transformer to 50Ω coaxial line.



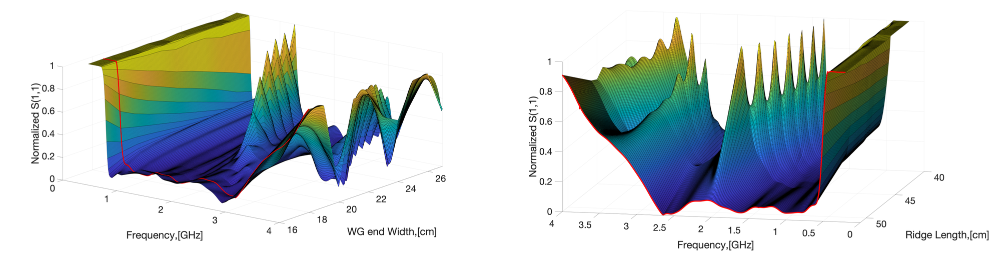


Figure 3: Normalized S(1,1) parameter dependence on variation of the parameters: the gap between the ridge and WG wall, coaxial probe position dz, WG end width and ridge length respectively.

At the ending of the inner conductor of the coaxial line, a cone-like ending was introduced. The probe dimensions, such as cone radius and height, were studied for optimization. Variations to the back-cavity dimensions were also studied, Fig.3.

Full Geometry Simulations

A single cell cavity without HOM dampers was simulated first during the numerical simulation process to determine a maximum shunt impedance of 10 MΩ. (R/Q = 238 Ω, Q_0 = 42 000, TM_{010}). After the HOM dampers had been optimized for a wide frequency span from 420 MHz to 3 GHz, the full structure was analyzed using different numerical simulations.

After the waveguide transmission line structure was already optimized, we continued studying the WG longitudinal position variation influence on the longitudinal shunt impedance for several HOMs that have relatively higher impedances across the resonator in the case of orthogonally located WG's Fig.4

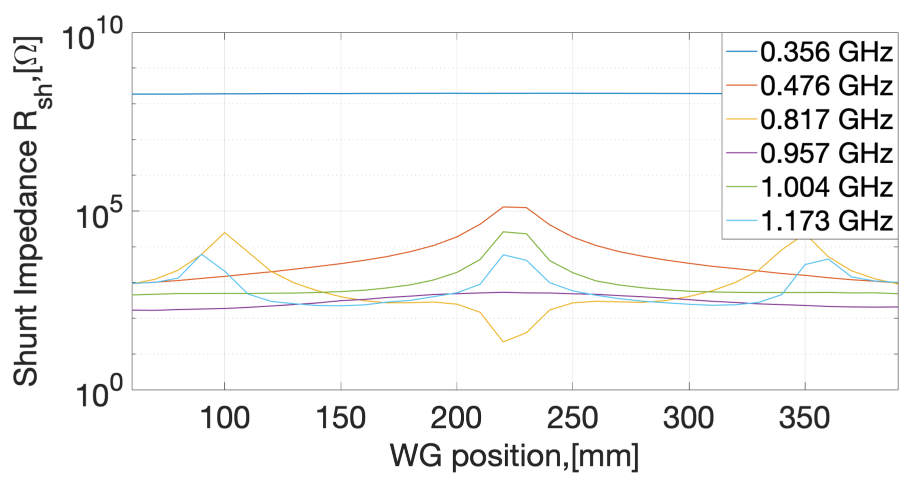


Figure 4: Longitudinal shunt impedance dependence on the position of the WG along the resonator

Different arrangements of the resonator and dampers were studied, mainly when the waveguides are perpendicular to the central axis and tilted. Fig.5 represents different alignments of the waveguides act on the longitudinal shunt impedances of the resonant modes.

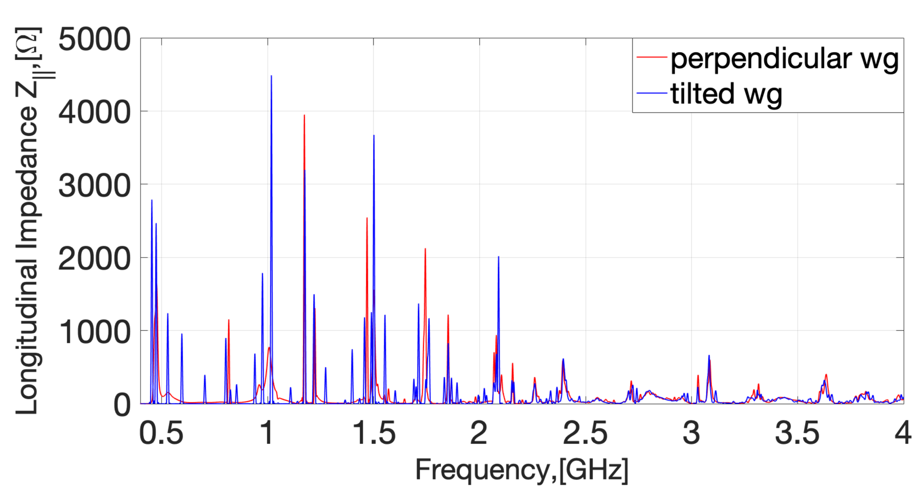


Figure 5: Longitudinal impedances for perpendicularly and tilted aligend waveguides.

The beam simulated was a 10 mm long gaussian pulse containing 1pC of charge. When the beam passes through the structure with a nonsymmetric geometry, even if it travels along the central axis in the beam pipe, a constant term caused by the transverse wakefield is present. Fig. 6 displays the transverse monopole wake potential in .

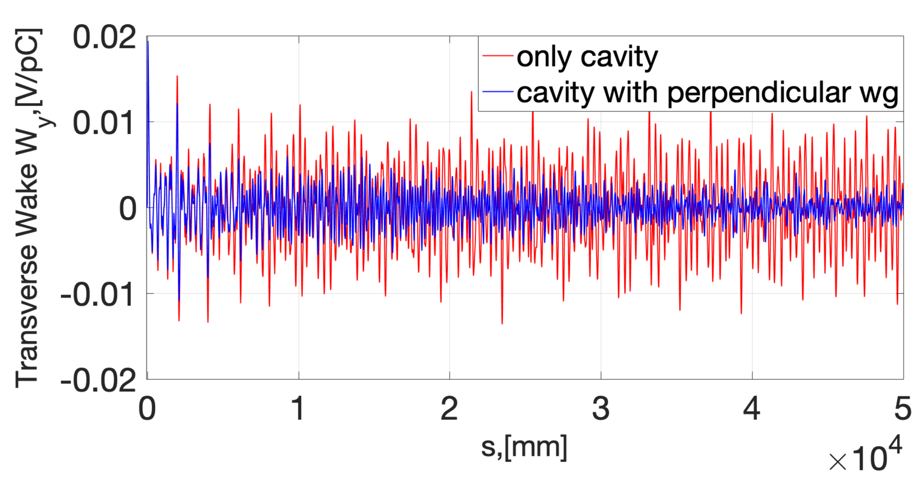


Figure 6: Transverse monopole wakefield potential.

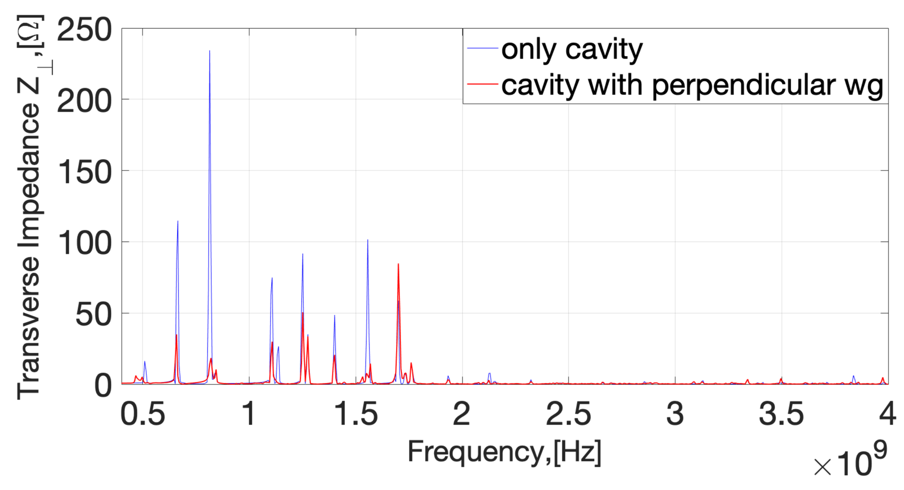


Figure 7: Transverse monopole impedances.

An asymmetric input in the structure can also be considered when the beam head particles are placed off the central axis. It will result in asymmetries in the RF fields and also excite the dipole modes that will transversely kick the beam. The in-phase component will kick the beam relatively uniformly; the out-of-phase component will kick the head and tail differently, resulting in emittance growth.

Taking the wake impedances Fig.7, we can see the induced modes in the prototype that generate transverse kicks and how damping waveguides are acting on them.

Fig.8 displays how perpendicular and tilted waveguides damp the dipole impedances.

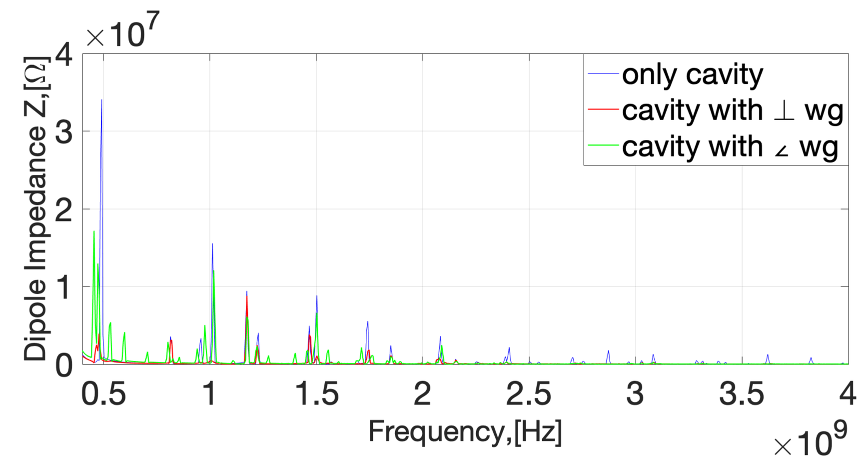


Figure 8: Dipole impedance

Table 1: Loaded Cavity HOM Properties

Mode Freq./GHz	R/Q Ω	Undamped Q	Damped Q perp. wg
0.476	4.88	34782	260
0.817	4	47511	800
0.957	0.9	57376	500
1.004	0.7	36969	370
1.173	5	66449	360
1.223	0.9	46709	1400
1.469	2.0	51519	1300
1.501	0.8	70188	800
1.568	0.3	111994	150

Conclusions

A modified broadband waveguide to coaxial line transition has been adopted for the nosecone cavity. The simulation results for the transition line present a low-level reflection coefficient on a wide frequency band, practically, starting from the fundamental mode till the beampipe cut-off frequency. The considered design is relatively simple and reliable. Furthermore, in advance of other comparable devices, there is no need to place any dissipating ferrite materials.

While optimizing the whole structure, the waveguide position concerning the cavity body was studied. The longitudinal and transverse beam coupling impedances, as well as wakefields, were calculated. Different configurations of mutual compositions between the cavity and waveguides were studied. The suppressor waveguides demonstrated the ability to reduce the quality factor of HOM by several order of magnitude table 1.

References

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