

IMPEDANCE MEASUREMENTS OF A HOM-DAMPED LOW POWER MODEL CAVITY*

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Abstract

In the frame of a European Community funded project a higher order mode (HOM) damped normal conducting 500 MHz cavity is under development optimized for the use in 3rd generation storage ring light sources. The relevant HOM-impedances have been measured with a fully scaled low power model made from aluminium. By using a cutoff frequency of 615MHz for the damping waveguides we have found a good compromise between the preservation of the accelerating mode impedance and the efficient broadband damping of HOM's. Detailed experimental results are presented and compared with numerical simulations.

1 INTRODUCTION

In undulator dominated 3rd generation storage rings the beam induced coupled-bunch instabilities driven by the narrowband HOM's of rf-cavities can severely limit the quality of the photon beams. Thus strong damping of all relevant cavity HOM's is a straight forward solution to avoid such instabilities. Based on numerical simulations [1] a cylindrically shaped 500MHz HOM-damped cavity was optimized with special emphasis on conceptual simplicity, low investment cost and a compact layout for compatibility with such cavities in existing storage ring tunnels (see Fig. 1). Detailed measurements have been performed for a fully scaled aluminium cavity to verify the promising impedance estimates of the simulations. A high power prototype cavity made from OFHC copper is under fabrication designed for 100kW input power [2] and for a max. gap voltage of 850kV.

2 CAVITY DAMPING SCHEME

The prototype cavity uses three tapered circular double ridged waveguide to coaxial transitions (CWCT's) as HOM-couplers [3]. They are spaced by 120° around the cavity circumference to facilitate the energy extraction of differently polarized transverse HOM's and shifted away from the cavity equator in axial direction to enable coupling to both symmetric and anti-symmetric HOM-field distributions (with respect to the longitudinal midplane). In this manner all critical beam induced HOM's couple to the 1st waveguide mode (TE₁₁-like) of the CWCT's. The CWCT internal ridge profile is shaped such that a constant cutoff is maintained all along the tapered section (see Fig. 2), which provides a broadband transmission characteristic with negligible mode conversion [3]. A cutoff frequency of $f_c=615\text{MHz}$ has been chosen finally as a compromise between a high

damping efficiency for the low frequency HOM's and a high shunt impedance for the fundamental accelerating mode.

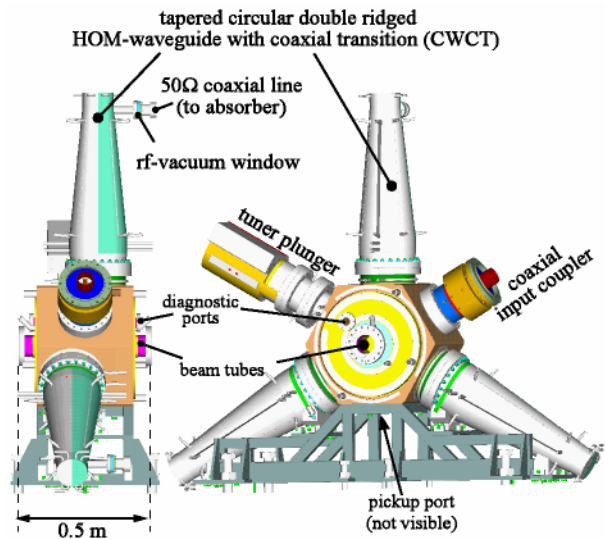


Figure 1: The 500MHz HOM-damped cavity assembly.

At the end of the tapered waveguide the TE₁₁-like mode is transformed to the TEM-mode of a 7/8" EIA standard 50Ω coaxial line by means of a transformer section. Thus HOM-energy can be extracted from the cavity and dissipated efficiently up to the relevant beam tube cutoff ($f_{TM01}=3.1\text{GHz}$) by means of external 50Ω absorbers, which are separated from the vacuum via broadband ceramic rf-windows.

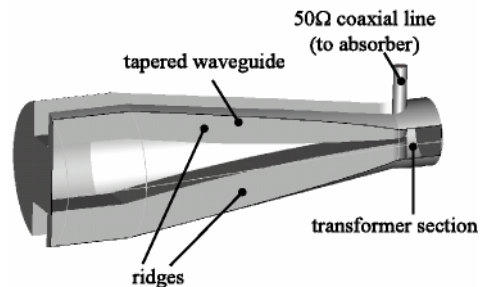


Figure 2: Schematic view inside a CWCT.

The length of the CWCT's has been chosen to limit the fundamental mode power leakage to about 1kW per absorber at 100kW cavity input power. This has been

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verified by measurements for the low power model scaling the result to this power level and taking the higher copper conductivity into account. Additional power originating from HOM's has been assessed analytically to be well below 1kW [4] for different design currents and fill patterns of modern storage rings. Thus commercially available 50Ω absorbers can be used as loads.

3 OPTIMIZATION STRATEGY

3.1 Simulations

Extensive numerical work has been done to optimize the cavity shape and the location of the damping waveguides [5] using MAFIA 3D time domain (T3) calculations to enable the simulation of broadband external damping measures [6]. Results have been improved iteratively by means of the beam coupling impedances, which can be evaluated from a Fast Fourier Transform of the computed wake potential induced behind the leading charge. However, the enormous amount of different optimization steps prevented from modelling the complex CWCT shapes, which would have led to prohibitively long calculation times. Homogeneous double ridged dampers were used instead (*simplified model*) with an ideal absorbing boundary at the end of the waveguides, i.e. $S_{11}=0$ just for the 1st propagating TE₁₁-like mode to resemble the CWCT characteristic as close as possible. Simulations indicate that HOM impedances can be reduced to a level of 2kΩ and 50kΩ/m for longitudinal and transverse HOM's respectively based on this damping scheme [1].

3.2 Initial Experimental Results

For the low power prototype cavity CWCT's with a cutoff of $f_c=650$ MHz have been used initially. Impedance measurements up to 1.6 GHz were carried out applying a "bead pull" method to probe the electric field of critical HOM's [7]. The TM₀₁₁-like mode ($f=699$ MHz) with the usually highest R/Q-factor of all monopole HOM's could be damped down to a level of 1.7kΩ. However, a coexisting TM₀₁₁-like "persistent mode" (*PM*) has been measured with a prohibitively high impedance of 36kΩ at 654 MHz not predicted by the *simplified model*.

Table 1: Measured persistent mode parameters

f_c [MHz]	f [MHz]	Q_l	R/Q [Ω]*	R [kΩ]*
650	654	1290	28.2	36.4
625	639	820	12.7	10.4
615	634	383	10.0	3.8

* $R=U_{\text{eff}}^2/2P_v$ with U_{eff} =effective voltage, P_v =power loss

It has been verified, that the *PM* does not exist in the cavity with closed HOM-ports and is due to the damping waveguides themselves. As the *PM* "sticks" to the cutoff, the energy propagation to the external loads is reduced causing a relatively high loaded quality factor (Q_l) and

consequently a higher impedance $R=(R/Q)*Q_l$. Therefore we lowered the CWCT cutoff and hence the *PM* frequency with the aim to convert the field pattern to a more TE₁₁₁-like nature, as such modes resonate at lower frequencies and exhibit much lower R/Q-factors. In fact the *PM* impedance could be reduced to 3.8kΩ resonating at 634MHz with a final choice of $f_c=615$ MHz as summarized in Table 1.

4 FINAL RESULTS

The unexpected persistent mode phenomenon has shown that the use of CWCT's as HOM-couplers can lead to results significantly apart from the predictions of the *simplified model* as the amount of HOM-energy that can be extracted from the cavity is reduced by the tapered waveguides. To evaluate the related impedance increase, extensive measurements have been carried out for the low power model cavity with the final choice of $f_c=615$ MHz. In addition long term MAFIA T3 calculations have been performed for a more realistic model, this time including the complex CWCT shape ("*realistic model*").

In Fig. 3 the measured impedances are presented together with the calculated impedance spectra for the *simplified* and *realistic model* respectively. Measurements reveal that a broadband damping efficiency of all HOM's is provided with impedances reduced to a level of 4kΩ and 170kΩ/m for the most dangerous longitudinal and transverse HOM's respectively.

4.1 Numerical and Experimental Issues

For the *realistic model* ~18 million mesh points (applying one symmetry plane) have been used exploiting our PC capabilities, but the complex CWCT shapes might still not be discretized satisfactorily to avoid numerical artefacts especially at higher frequencies. Actually some of the higher impedances could not be confirmed by the measurements as indicated in Fig. 3. Nevertheless the *realistic model* has predicted impedances in principal agreement with experimental results, also confirming the relatively high impedance of the persistent mode.

As all HOM's are strongly damped, the accuracy of the measurements suffers from overlap of adjacent modes. E.g. for the monopole HOM at 2.64 GHz with a relatively high longitudinal impedance we have observed large field amplitudes in the beam tubes, which belong to a propagating TE-like dipole mode in the vicinity measured at the same time. The use of pick-up probes with loose coupling therefore is essential for the measurement, which compromises however the signal-to-noise ratio. Major inaccuracies were found for HOM's with rather low impedances fortunately out of interest. Due to the broken symmetry of the cavity, the electrical and geometrical (beam) axis can differ considerably depending on the HOM field pattern. Hence transverse modes can exhibit significant longitudinal field components on the beam axis, which has been verified experimentally. Transverse HOM's with such behaviour

have been included in the longitudinal impedance spectrum. Measurements were also complicated by many low impedance HOM's excitable by the pick-up probes but not relevant for the beam even when left undamped. Actually 3D eigenmode calculations with Microwave Studio [8] up to 1.6GHz (full model, but no damping

measures possible in frequency domain) revealed the existence of about 100 modes. In that spectral region all critical HOM's could be identified unambiguously by comparing measured and calculated field patterns. This also gives confidence in experimental results at higher frequencies not surveyed by eigenmode calculations.

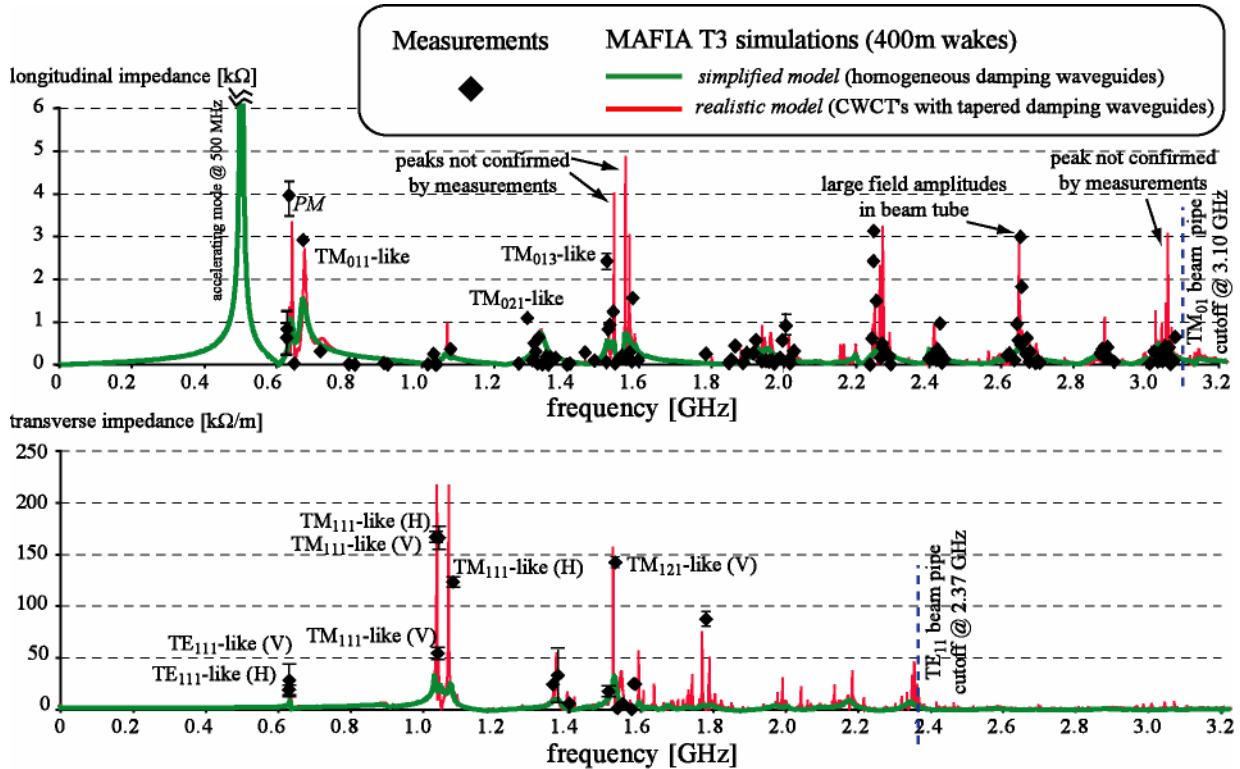


Figure 2: Measurement results (diamonds) for longitudinal (top) and transverse impedances (bottom) together with the predicted impedance spectra (lines) of the *simplified* and *realistic* MAFIA T3 model respectively. The European definition of the shunt impedance $R=U_{\text{eff}}^2/2P_V$ is assumed with U_{eff} =effective voltage, P_V =power loss.

5 CONCLUSION AND OUTLOOK

Detailed impedance measurements have been performed for a 500MHz low power HOM-damped cavity, which makes use of tapered CWCT's as HOM-couplers. With these couplers the HOM's are damped down to a level of 4kΩ and 170kΩ/m for the most critical longitudinal and transverse HOM's respectively. The measurement results are in principal agreement with numerical estimates for the *realistic model*. A first high power prototype cavity made of OFHC copper is under manufacturing encouraged by the promising results. Benchmark measurements for the most critical HOM's, high power conditioning, and first beam tests in the DELTA ring in Dortmund/Germany are scheduled for the second half of 2003.

In parallel investigations are performed to design a more homogeneous damping waveguide with internal loads as an alternative to the CWCT's. The aim is to a) closer resemble the *simplified model*, which indicates that longitudinal and transverse HOM's can be further damped

to a level of 2kΩ and 50kΩ/m respectively and b) to reduce the investment costs for the HOM-couplers.

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