NUMERICAL SIMULATIONS OF A HOM DAMPED CAVITY*

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Abstract

To investigate the optimisation of a Higher Order Mode (HOM) damped cavity, a 500MHz cavity with nose cones was chosen as a basis. An aluminium model has been manufactured, which enables correlation of numerical simulations using the 3D frequency and time domain solvers of the MAFIA code [1]. The overall damping efficiency in terms of the broadband coupling impedances have been calculated for a “bare” cavity i.e. with all open ports shorted and for a cavity with a single HOM damping waveguide attached to the cavity body. This paper details the simulation techniques employed in modelling such an electro-magnetically complicated structure, as well as providing preliminary results of the measurements of the model cavity.

1 INTRODUCTION

RF cavity HOMs in the context of modern 3rd generation synchrotron light sources, are a major cause for concern in terms of the beam stability that can be achieved. Coupled-bunch instabilities can limit the photon beam brightness, and a reduction of the HOMs impedances, that can be driven by the electron beam, is desirable to raise the beam current instability thresholds of the accelerator. As part of an EC funded RTD project a normal conducting cavity will be designed, which damps the HOM impedances, consequently providing a more stable accelerating cavity system.

A low power aluminium prototype cavity, equipped with six open ports has been manufactured to study the damping efficiency of these parasitic HOMs (see Figure 1a). The cavity geometry employs nose cones to improve the fundamental accelerating (TM_{010}) mode shunt impedance (see Figure 1b). The three HOM damping waveguides are positioned on the aluminium prototype cavity equator, equispaced azimuthally by 120° [2] and are geometrically outlined as double-ridged Circular Waveguide to Coaxial Transitions (CWCT). The assembly is also tapered to deliver a broadband power coupling to an external load (see Figure 2). The design of such a waveguide has been optimised numerically [3], by characterisation of the S-parameter $|S_{11}|$ reflection response up to 3GHz, which is well above the TE_{11} and TM_{01} beam pipe cut-off frequencies.

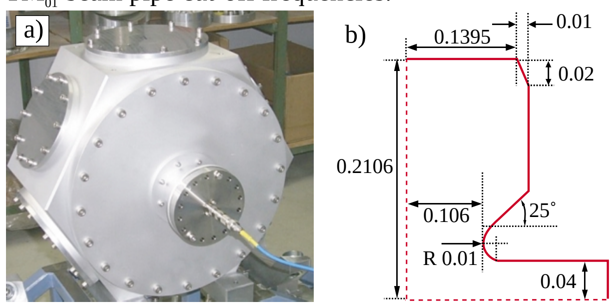

Figure 1: a) Bare aluminium prototype cavity b) 500 MHz cavity internal geometry profile

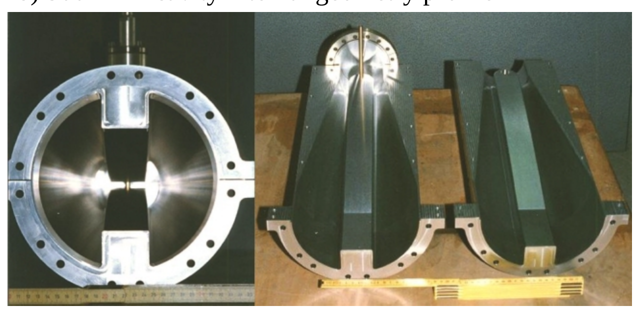

Figure 2: CWCT damper assembly

2 SIMULATIONS

In the following the bare cavity and the cavity with a single HOM damping waveguide will be referred to as the *undamped* and *damped* cavity respectively. All calculations were performed in 3D, in frequency and time domain, using the E3 and T3 MAFIA solvers respectively. In order to minimise the CPU overhead required in performing such calculations, only half the 3D structure was modelled (see Figure 3).

2.1 Frequency Domain

For the frequency domain simulations the cavity was modelled by applying a transverse symmetry midplane. In the E3 solver all boundary planes can only be specified as ideal electric or magnetic boundaries [1]. The *undamped* cavity is modelled with all ports electrically

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shorted. For the *damped* cavity simulation, it is not possible to simulate a broadband match at the HOM waveguide boundary and so for simplicity, the HOM taper was shorted at the end without the inclusion of the coaxial transition (see Figure 3a).

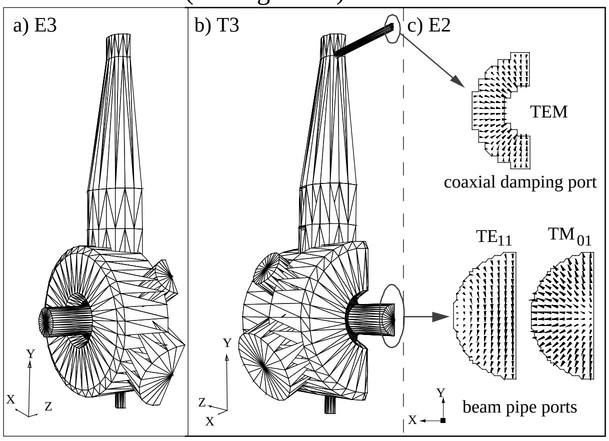

Figure 3: Half structures of the *damped* cavity as modelled for a) frequency (E3) and b) time domain (T3) calculations, c) 2D waveguide eigenmodes

Using the E3 solver, two separate simulations with a magnetic and an electric boundary condition at the symmetry midplane were performed in order to calculate all possible resonating modes up to a given frequency. These eigenmodes can then be divided into two groups, which differ by the parity of their longitudinal electric field component $E_{||}(z)$ with respect to the symmetry plane i.e. for symmetric modes, $E_{||}(z)=E_{||}(-z)$, whereas for anti-symmetric modes, $E_{||}(z)=-E_{||}(-z)$. Due to the complex shape of the cavity, a convention has been chosen for mode identification as n-E-m and n-M-m [4], where n is the azimuthal dependency (0=monopole, 1=dipole etc.), E or M is the electric or magnetic boundary condition assumed at the symmetry plane and m is a sequential index (m=1,2,…) for each n. For example the TM_{010} accelerating mode is denoted as 0-E-1.

2.2 Time Domain

For the time domain simulations, the full 3D structure in longitudinal direction is necessary (see Figure 3b) [1]. An advantage of the T3 modelling technique compared to the E3 simulations is the possibility of defining open boundary conditions. The coaxial output port at the end of the damping waveguide thus can be defined as an infinitely long waveguide port (i.e. VSWR=1). To simulate the waveguide boundary condition, a 2D slice at the waveguide port is cut out of the 3D mesh, for which the 2D eigenmodes are calculated using the MAFIA E2 eigenmode solver (see Figure 3c). The same procedure is applied to the input and output beam tubes. All waveguide modes are then loaded into the T3 solver along with the 3D-cavity model for the time domain integration. Ideally, for an open boundary condition, all propagating waveguide modes and non-propagating modes with relatively low attenuation constants in the frequency range of interest should be included. In our case, we limited the frequency range to f_{max}=3GHz as this was the upper frequency for which the CWCT was optimised. For the coaxial port, it is simply the TEM mode and for the beam ports, the TE_{11} and TM_{01} modes that are required to be loaded into T3, all other modes can be neglected as they have relatively high attenuation constants.

A longitudinal gaussion bunch distribution is launched into the cavity (at t_0=0s and β=1) to excite the wakefields. For this structure we excite the cavity along the z-axis, down the centre of the beam tube in order to calculate the longitudinal wakefields and offset vertically to probe the transverse acting HOMs. The line current I(t) used for the excitation in MAFIA and its Fourier Transform (FT) are:

$$I(t) = \frac{cq}{\sqrt{2\pi}\sigma_s} e^{-\frac{1}{2}\frac{(ct)^2}{\sigma_s^2}} \overset{FT}{\Rightarrow} I(\omega) = qe^{-\frac{1}{2}\frac{(\sigma_s\omega)^2}{c^2}}, \quad (1)$$

where q is the total charge and σ_s the rms bunch length, for which σ_s=10mm has been assumed. The longitudinal wakefield can then be computed. In fact MAFIA calculates the wake function $W_{||}(x,y,s)$ including the dependency on the bunch co-ordinate system s = c/t (in metres) within a specified range behind the bunch excitation. Once the wakefield is computed, a Fast Fourier Transform is applied to obtain the longitudinal broadband impedance spectrum $Z_{||}(x,y,\omega)$ [5], which we normalize by the bunch spectrum:

$$Z_{||}(x,y,\omega) = \frac{1}{cqe^{-\frac{1}{2}\frac{(\sigma_s\omega)^2}{c^2}}} \int_{-\infty}^{+\infty} ds\, W_{||}(x,y,s)\, e^{-i\frac{\omega}{c}s} \quad (2)$$

and for the transverse case:

$$Z_{\perp}(x,y,\omega) = \frac{Z_{||}(x,y,\omega)}{kr_y^2}, \quad (3)$$

where k=ω/c is the wave number and r_y the vertical offset. The bunch is launched either on or off axis , i.e with r=0 to probe the longitudinal HOMs and in our case r_y=30mm for the transverse. For the transverse HOMs we enhance mainly the excitation of vertically polarized dipole modes, since this gives stronger coupling to the HOM waveguide damper. A beam on axis yields the strongest excitation of TM monopole modes, but it is clear that, due to the lack of symmetry caused by the additional ports, the transverse modes can also possess significant longitudinal electric field components on axis.

3 RESULTS

To resolve the resonances in the impedance spectrum adequately, the wakefields have to be computed up to rather long distances behind the exciting bunch. Figure 4 shows the longitudinal impedance spectra for the *undamped* and *damped* cavity using 400m wakes, which gives a reasonable resolution of the HOMs. The strongest resonances belong to TM-monopole modes, which could be identified with the help of E3 calculations.

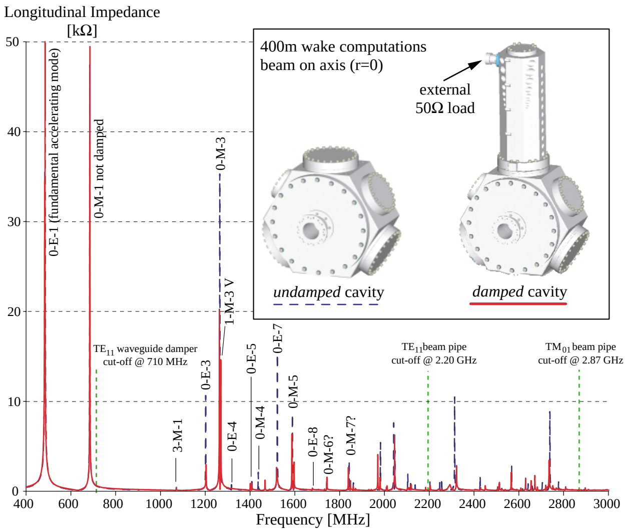

Figure 4: Longitudinal impedance spectra for the *undamped* and *damped* cavity (400m wakes, r=0)

The most dangerous mode is the anti-symmetric 0-M-1 mode around f=683 MHz, which is below the CWCT's cut-off and therefore is unaffected. Beside the monopole modes also the 3-M-1 sextupole mode and the 1-M-3 dipole mode were excited. Verified by E3 calculations, the latter one exhibits a stronger $E_{\|}$-field in the presence of the waveguide damper and therefore in fact is only visible for the *damped* cavity.

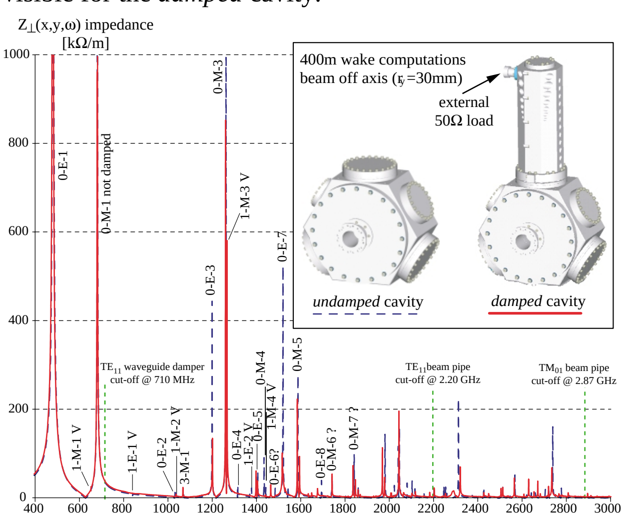

Figure 5: $Z_{\perp}(x,y,\omega)$ impedance spectra for the *undamped* and *damped* cavity (400m wakes, r_y=3cm)

In Figure 5 the $Z_{\perp}(x,y,\omega)$ impedance spectra for the *undamped* and *damped* cavity are shown using 400m wakes with a beam vertically offset by r_y=3cm. Since in this case both the monopole and the transverse modes are excited, it should be mentioned, that Figure 5 represents the transverse impedance for transverse modes only. From Figures 4 and 5 it can be seen, that an improvement of the overall damping efficiency is achieved when the CWCT is attached to the cavity body. A relatively strong damping is obtained for symmetric modes, since they possess longitudinal electric field components $E_{\|}(z)$ around the midplane, which is in contrast to the anti-symmetric modes. These kind of field distributions preferably couple to the CWCT, when the ridges are orientated along the z-axis as in our case. Table 1 shows preliminary results of measurements for some of the modes calculated, which verifies the above statement.

Table 1: Measured and calculated frequencies and measured quality factors for some of the HOMs in the *undamped*/*damped* cavity respectively

mode	Frequency [MHz]			Q_0
	measured	E3	T3	measured
0-E-1	484.4/483.4	482.6/481.6	483.0/481.2	19566/19068
1-M-1 V*	652.0/652.5	653.1/653.4	654.3/654.6	20635/21435
0-M-1	688.7/689.1	684.6/684.8	683.1/682.5	17142/16967
1-E-1 V	836.8/n.v.**	837.9/833.6	840.5/n.v	26408/n.v.
0-E-2	1038.4/n.v.	1035.7/1022.6	1033.4/n.v.	18234/n.v.
1-M-2 V	1033.6/1033.7	1035.0/1035.0	1038.4/1037.9	20972/24749
3-M-1	1070.5/1069.2	1069.5/1067.3	1071.0/1069.5	23262/21829
0-E-3	1196.3/n.v.	1196.3/1195.4	1200.3/1202.2	30121/n.v.

*V = vertical orientation of mode, **n.v. = mode not visible after damping

4 CONCLUSION

In contrast to frequency domain calculations, the longitudinal and transverse impedance spectra obtained from MAFIA time domain simulations provide essential information for the characterization of a HOM damped cavity in one step. Therefore this method is a powerful tool for the numerical optimisation of the global HOM damping efficiency. The mode frequencies obtained in time domain (T3) and in frequency domain (E3) are in good agreement with the measurements, which is of great help for the identification of the measured modes.

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