IMPEDANCE MEASUREMENTS OF A HOM-DAMPED LOW POWER PROTOTYPE CAVITY FOR 3rd GENERATION SR SOURCES[*]

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Abstract

A higher order mode (HOM) damped 500 MHz accelerating cavity optimised specifically for 3rd generation synchrotron radiation (SR) sources has been proposed recently. Based on numerical simulations a full scale low power prototype cavity has been built to verify the numerical results by impedance measurements. Latter indicate, that the impedances driving longitudinal multibunch oscillations can be reduced down to a level of 2 kΩ·GHz as expected numerically, except a persistent mode close to the cutoff frequency of the HOM-dampers not predicted by the simulations. Details of the measurement are presented and possible cures are discussed to reduce the impedance of the persistent mode.

1 INTRODUCTION

Broadband HOM damped accelerating cavities are essential to exploit the full potential of state of the art 3rd generation SR sources. However, while the first HOM damped normal conducting single cell cavities have been developed in the last ten years for meson factories, such cavities have not been optimised for the specific needs of SR sources yet.

In the frame of an EC funded RTD project a 500 MHz cavity is under development to fill this gap [1]. Conceptual simplicity and a compact layout with an insertion length below 0.6 m were the essential criteria for the mechanical design in order to allow the installation of such cavities in existing storage ring tunnels. Great effort has been made to minimize the HOM impedances by optimising the cavity shape and the location of the waveguides [2] with the help of MAFIA 3D time domain calculations [3]. A high HOM damping efficiency is achieved using three double ridged circular waveguides. Simulations indicate, that the longitudinal and transverse HOM impedances are below 2 kΩ and 50 kΩ/m respectively in the frequency range up to the corresponding beam pipe cutoff. As a consequence all existing SR sources with 500 MHz rf-systems could be operated at their nominal design parameters by using this cavity design without being affected by longitudinal multibunch instabilities ([1], [4]).

2 THE LOW POWER MODEL

To verifiy the theoretical impedance estimates, a full scale aluminium prototype cavity has been built. The cavity body is of cylindrical shape utilising nose cones to optimize the fundamental mode shunt impedance. This cavity uses 3 Circular Waveguide to Coaxial Transitions (CWCTs) as proposed in [5] to couple to the HOMs and absorb their energy in external loads. The CWCTs are shifted parallel to the beam axis ending close to the side walls (one in opposite direction of the others) to improve coupling to anti-symmetric TM$_{0mn}$ like modes (odd n). This design has the conceptual advantage of a rather small insertion length as the CWCTs are oriented perpendicularly to the beam axis (see Fig. 1).

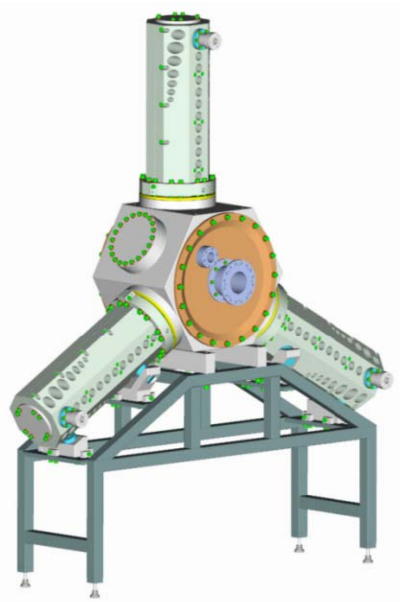

Figure 1: Model of the prototype cavity assembly.

The CWCTs are tapered with a symmetric double ridge profile (see Fig. 2) in order to keep the 1st waveguide mode cutoff frequency constant along the waveguide.

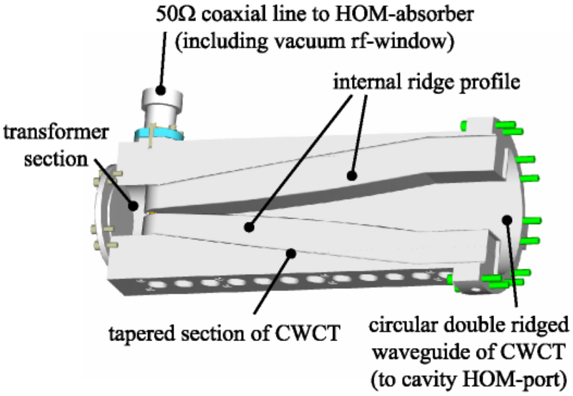

Figure 2: Cross section of CWCT.

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Complemented with a final transformer section this allows the broadband transmission of HOM-power to a 50Ω coaxial absorber. A waveguide cutoff of 650MHz was chosen in the first approach to damp all HOMs but keeping the fundamental mode trapped. The CWCTs have been optimized corresponding to this cutoff for a low reflection response at least up to the monopole cutoff of the beam tubes (Ø=74mm), i.e. 3.1 GHz (see Fig. 3).

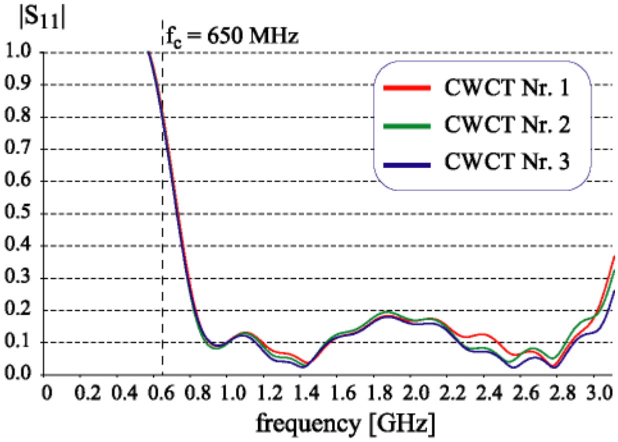

Figure 3: Measured reflection response of CWCTs including a commercial 7/8” EIA vacuum rf-window.

3 IMPEDANCE MEASUREMENTS

Impedance measurements have been started recently yet restricted to longitudinal modes located in the low frequency regime. First results are detailed below.

3.1 Measurement Method

To determine the shunt impedance of a HOM a dielectric “perturbation” object is pulled through the resonator to sample the longitudinal electric field $|E_z|$ ("bead-pull measurement"). Using a network analyzer the phase shift $\Delta\varphi(z_j)$ between two coupling probes (coupling factor k_1 and k_2) caused by the perturbation object has been detected at equidistant positions z_j (resolution Δz) along the cavity path of total length L. This method allows to pull the object continuously through the structure limiting the measuring time and therefore avoiding parasitic temperature drifts. The perturbation object is calibrated prior to the measurement in a pillbox resonator to account for its special shape and permittivity given by the perturbation constant α. For a mode with resonant frequency ω_0 and ohmic wall loss P_V in the cavity the shunt impedance R is then given by (european definition):

$$R = \frac{\left(\int_0^L dz\,|E_z|\right)^2}{2P_V} \approx \frac{(1+k_1+k_2)}{2\omega_0\alpha}\Delta z^2 \cdot \left(\sum_{j=0}^{L/\Delta z}\sqrt{\tan\Delta\varphi(z_j)}\right)^2. \qquad (1)$$

R can be transit-time corrected provided all sign changes of the electric field along the integaration path are known. For well damped modes this sometimes is not an easy task as the signal-to-noise ratio may be very low to distinguish between real sign changes or zeros of the electric fields. This favours the use of relatively large perturbation objects of high permittivity. On the other hand, the perturbation object has to be limited in size since large phase shifts $\Delta\varphi(z_j)$ should be avoided as a precondition of eq.(1). Thus, to obtain reliable results, coupling probes and perturbation objects of variable size have been used depending on the mode of interest. Stretched objects are preferable for modes with mainly longitudinal electric field components. By experience however, as the cavity is of broken symmetry even TM-like monopole modes might possess considerable radial electric field components and dipole modes might have longitudinal electric field components on axis. Therefore needle-shaped as well as disk-shaped objects were used in combination, which allows to determine the longitudinal field components only.

3.2 Results

Measurement results for longitudinal HOMs are plotted in Fig. 4 together with the calculated impedance spectrum, where the european definition of the shunt impedance $R=U^2/2P_V$ is assumed.

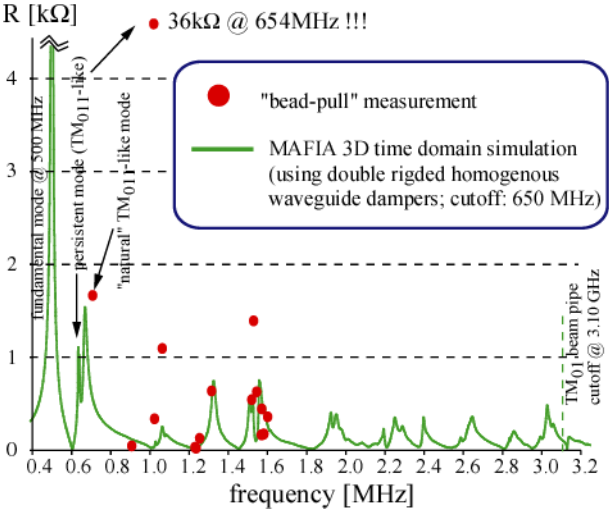

Figure 4: First impedance results of longitudinal HOMs in the HOM-damped cavity as measured (dots) together with the predicted impedance spectrum (line).

As can be seen, most HOMs are reduced down to a level of 2 kΩ·GHz in good agreement with the simulations, e.g. the TM_{011}-like mode could be well damped to R=1.7 kΩ @ 699 MHz. However as a surprise a second “persistent” TM_{011}-like mode showed up experimentally with R=36kΩ @ 654 MHz. Measurements revealed, that this mode does not exist in the “naked” cavity (all HOM-ports blanked) and is thus caused by the HOM-dampers themselves. On the other hand, the high impedance was not predicted by the MAFIA time domain calculations. Consequently the discrepancy must be due to the CWCT shape different from the simplified numerical model, as we have incorporated purely homogeneous double ridged waveguides ($|S_{11}|=0$) to allow an optimisation of the cavity within a realistic computation time [1]. Considering Fig. 3 a strong reflection has to be taken into account in reality as the persistent mode frequency is close to the CWCT cutoff yielding only a low group velocity. Thus this mode exhibits relatively low field amplitudes at the transfomer end section degrading the damping efficiency significantly compared to the simplified numerical simulation. To understand the nature of the persistent mode and to find possible cures, 3D eigenmode calculations have been performed using Microwave Studio (MWS) [6] regarding the full shape of the CWCTs. Different CWCTs of various cutoff frequencies have been incorporated (i.e. 650 MHz, 625 MHz and 615 MHz respectively).

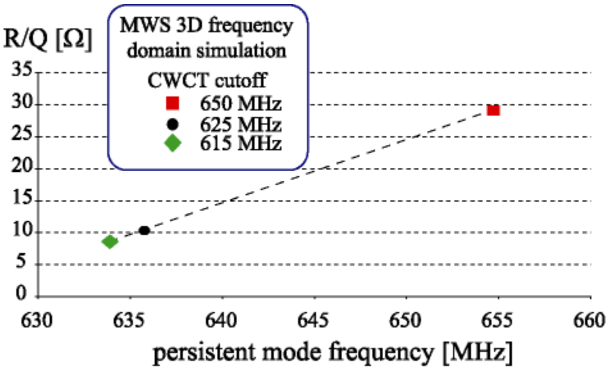

Figure 5: R/Q vs. resonant frequency of persistent mode using CWCTs of different cutoff frequency.

Figure 5 indicates, that by reducing the CWCT cutoff the resonant frequency as well as the R/Q-factor of the persistent mode is decreased. Thus a lower resonant/cutoff frequency seems to be favourable. As a benefit also the span between the persistent mode and cutoff frequency is increased. It has to be considered, that the cutoff frequency must not be reduced too strongly as the fundamental mode power leakage is enhanced simultanously. This effect can only be compensated by an appropriate increase of the total CWCT length [7], which may increase the loaded Q on the other hand. Based on these findings the cutoff of the existing CWCTs has been reduced from 650 MHz to 625 MHz. Table 1 gives the measured results, which also correspond well with the calculations in Fig. 5. In fact the impedance of the persistent mode could be reduced by a factor of 3.5 to about R=10kΩ. However we noticed, that the cutoff frequency is not constant but raises along the tapered section of the CWCT from 625 MHz to a maximum of 645 MHz due to details of the manufacturing process. Thus the cutoff frequency is partly above the persistent mode frequency of 639 MHz. This may deteriorate the Q_l considerably as the damping of the persistent mode is very sensitiv on the field amplitudes at the end of the CWCT.

Table 1: Measured parameters of the persistent mode before and after reduction of the CWCT cutoff frequency

cutoff of CWCTs [MHz]	f [MHz]	Q_l	R/Q [Ω]**	R [kΩ]**
650	654	1290	28.2	36.4
625*	639	820	12.7	10.4

*homogeneous waveguide length increased by 10cm
** transit-time corrected

Therefore new CWCTs with a “constant” 615 MHz cutoff are under fabrication to further reduce the R/Q as well as the Q_l, since the mode frequency is then located above the cutoff up to the end of the CWCTs. We do not expect large impedance variations concerning other HOMs as the geometrical modifications are not significant.

4 CONCLUSION AND OUTLOOK

A low power prototype HOM-damped cavity has been built based on numerical simulations. Verified by measurements the longitudinal HOMs are damped below 2 kΩ as predicted numerically, except for a persistent mode. This mode does not exist in the cavity with blanked HOM-ports and thus is caused by the CWCTs themselves. As its resonant frequency is close to the CWCT cutoff the damping efficency is degraded significantly. A reduction of the cutoff frequency to 625 MHz allowed to reduce its impedance by a factor of 3.5 to about R=10kΩ. To further reduce the impedance new CWCTs will be fabricated with a constant cutoff of 615 MHz, which both lowers the R/Q and loaded Q of this mode. Further impedance measurements including dipole modes are in progress.

5 REFERENCES

[1] F. Marhauser, E. Weihreter, D.M. Dykes, P. McIntosh, Proc. of 19th PAC 2001
[2] F. Marhauser, E. Weihreter, BESSY-016-July-2001, Internal Report
[3] X.E. Lin, K. Ko, C.K. Ng, Proc. of 16th PAC, Dallas (Texas), USA, 1-5 May 1995, pp. 1744-1746
[4] E. Weihreter, F. Marhauser, Proc. of the Shanghai Symposium on Intermediate Energy Light Sources, SSRC-02-1, 2001, p 161
[5] E. Weihreter, S. Küchler, Y.C. Tsai, K.R. Chu, Proc. of 6th EPAC, Stockholm, Sweden, 22-26. June 1998, vol. 2, p. 2065
[6] Microwave Studio (PC release 3 RC1), CST, Darmstadt, Germany 2000
[7] C.C. Yang, C. Sung, K.R. Chu, Y.C. Tsai, C. Wang, E. Weihreter, F. Marhauser, these proceedings