HIGHER ORDER MODES SIMULATION AND MEASUREMENTS FOR 2400 MHz CAVITY*

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Abstract

In the frameworks of the High Luminosity LHC upgrade program an application of additional harmonic cavities operating at multiples of the main RF system frequency of 400 MHz is currently under discussion. The 800 MHz superconducting cavities with grooved beam pipes were suggested as one of the design options. A scaled aluminum prototype with a frequency of the operational mode of 2400 MHz was manufactured for testing the results of simulations. The load reflection coefficient measurements were performed as well as the Q_{load} measurements for cavities with the load. Here we discuss the prototype design and report the obtained measurement results.

INTRODUCTION

At present the project aimed at Large Hadron Collider luminosity upgrade (HL-LHC) is being developed at CERN [1]. The implementation of 800 MHz harmonic cavities in LHC should provide a possibility to vary the length of colliding bunches in LHC which can lead in number of positive effects [2]. In order to supply the required harmonic voltage several single cell superconducting cavities are to be used.

One of the main goals of the cavity design is to fulfill strict Higher Order Modes (HOM) damping requirements. Several techniques for HOM damping such as beam pipe grooves, fluted beam pipes, ridged beam pipes etc. were investigated and compared [3]. In our opinion the solution with grooves (see Fig. 1), similar to that used in KEKB [4], is preferable due to the structure cylindrical symmetry, design simplicity and absence of dangerous HOMs. That is why in order to check the simulation results and to investigate eventual HOM properties the scaled version of this cavity was manufactured.

SIMULATIONS

Based on the results obtained during the calculations carried out with the MWS [5] and ABCI [6] codes the dimensions of the grooved beam pipe were chosen in such a way that the external quality factor of the most dangerous dipole HOMs was below 100 and below 1000 for HOMs in the higher frequency range. As it is seen in Fig. 2 the wake potential decays almost to zero when the distance between bunches is 15 m and on the graph of longitudinal impedance there are no sharp peaks corresponding to the HOM with high Q values. This has been achieved due to the fact that the cut-off frequency of the drift tube is lower than the frequency of HOMs.

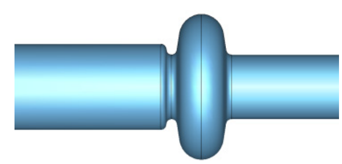

Figure 1: Cavity with grooved beam pipes.

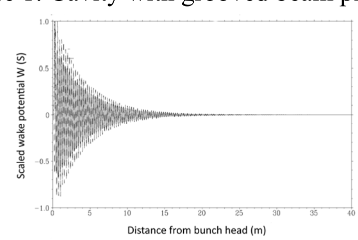

Figure 2a: Transverse wakefield potential in the cavity with the grooved beam pipe.

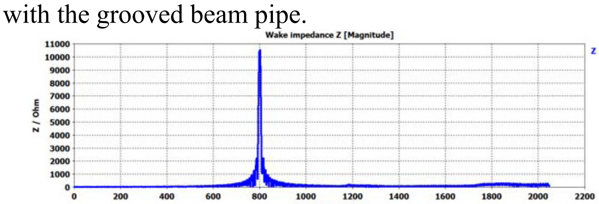

Figure 2b: Longitudinal impedance in the cavity with the grooved beam pipe.

In order to verify the results obtained by numerical simulations a scaled aluminium cavity prototype with the frequency of the fundamental mode of 2400 MHz was built. The prototype was designed in a modular form (Fig. 3, 4) so that it is possible to carry out measurements for different lengths and shapes of the drift tubes and to further carry out measurements for a chain consisting of two such cavities. The prototype assembly consists of the beam pipe with a larger radius, the cavity body, the beam tube with a smaller radius having a feedthrough for power input and two shorting plates.

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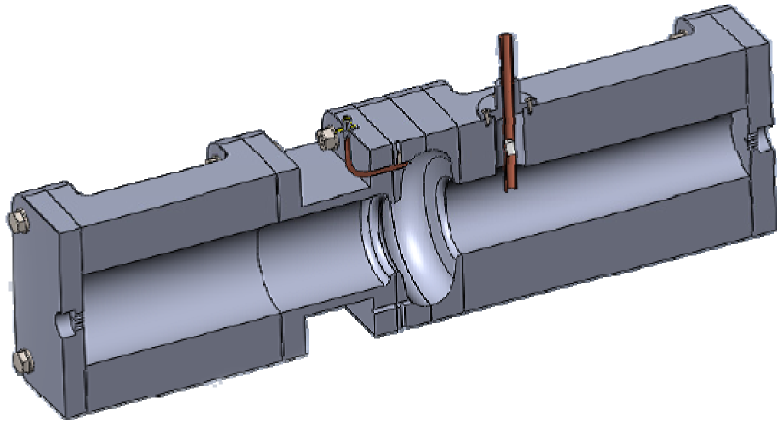

Figure 3: Scheme of the cavity prototype.

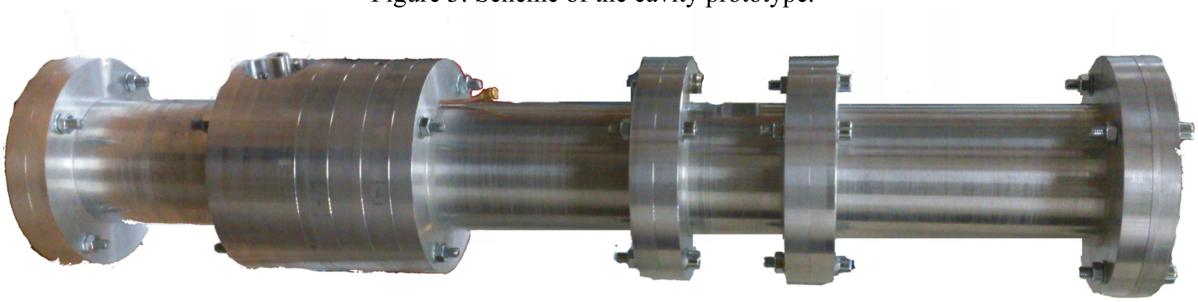

Figure 4: General view of the assembled prototype.

HOM LOAD MEASUREMENTS

In order to achieve a high HOM damping efficiency a load with the lowest possible reflection coefficient should be produced since in namely this case all the stored energy of these modes will be dissipated in the load.

A cone coated with a layer of graphite was manufactured for the use as a load for the HOM damping. Before carrying out experiments to determine the effectiveness of the HOM damping a dedicated study was conducted for measuring the reflectance of the loads with different length and the thickness of the graphite coating.

The experimental scheme is shown in Fig. 5. The size of the antenna and the position of the shorting plunger was selected in such a way that the reflection from the adapter would be minimal (<-20dB) on the frequency of 3120 MHz which is the middle frequency between the two dipole modes with the highest R/Q ratio. After that by moving the conical load toward the adapter by λ/4 the reflection coefficient from the load was measured.

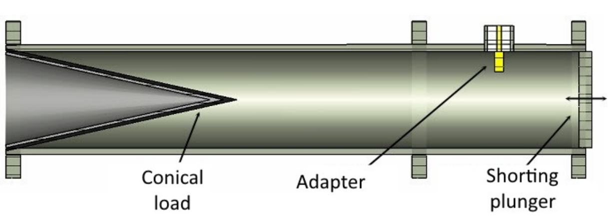

Figure 5: The scheme of the reflection coefficient measurements of the load.

The measurement results of the reflection coefficients are presented in Table 1. The results correspond to the TE11 mode on the frequency of 3120 MHz.

Table 1: Reflection Coefficients Achieved for Different Length of Load and Graphite Thickness

Load length, mm	S_{11}, dB	Graphite thickness
181	-9,4	40-60
181	-13,4	110-120
181	-22,7	120-170
240	-12,3	50-70
240	-22,3	100-110
240	-25,3	130-150

Q_L MEASUREMENTS

The load with the lowest reflection coefficient (-25.3 dB) was chosen to perform the experimental measurements of HOM damping efficiency. The conical load was placed in the drift tube with bigger radius.

First, the measurements were performed for the length of the drift tube of 200 mm (Fig. 6). The Q's of the HOM were significantly reduced. But it also appeared that the Q-factor of the operation mode was also affected. For this reason the length of the drift tube was increased up to 400 mm (Fig. 7). After the increasing of the drift tube length the Q_{load} of the operation mode returned to its initial value while the HOM Q's values remained the same.

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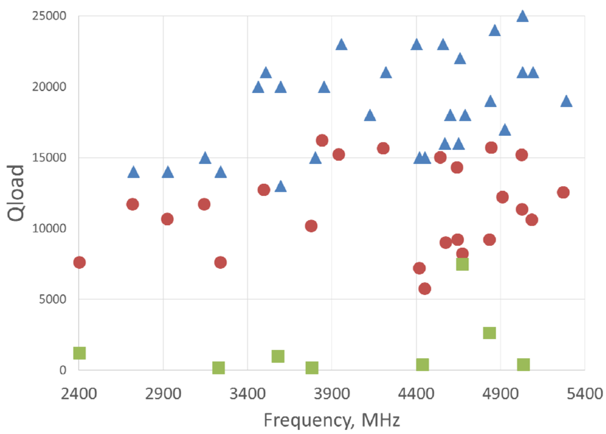

Figure 6: Q_{load} of the cavity with a grooved pipe length of the drift at the drift tube 200 mm. Triangles – Q_0 calculation, circles - Q_0 measurements, square - Q_{load} measurements.

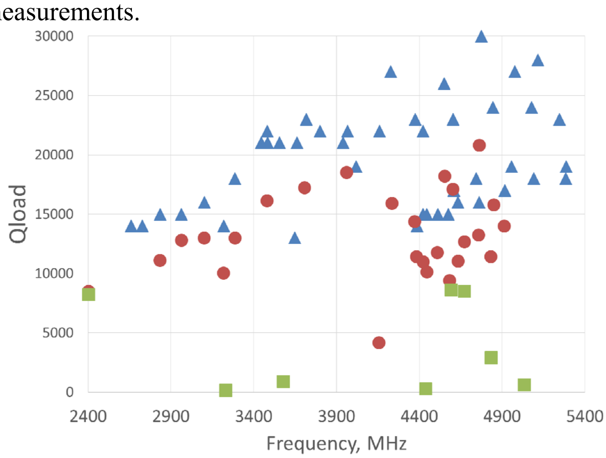

Figure 7: Q_{load} of the cavity with a grooved pipe length of the drift at the drift tube 400 mm. Triangles – Q_0 calculation, circles - Q_0 measurements, square - Q_{load} measurements.

Also a comparison was made between calculated Q_{load} in the CST program with measurement results. The comparison results are shown in Figs. 8 and 9.

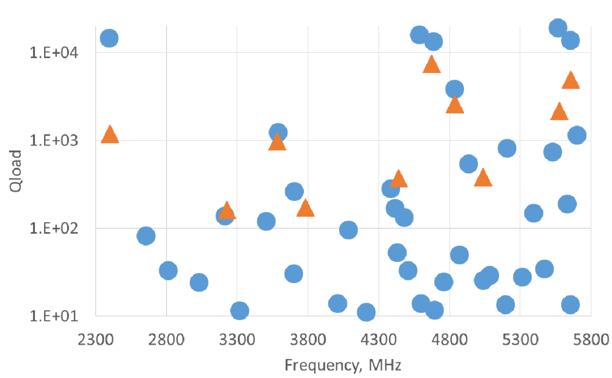

Figure 8: Comparison of CST Q_{load} and measured Q_{load} for the cavity with grooved beam pipe (200 mm). Circles – CST Q_{load}, triangles – measured Q_{load}.

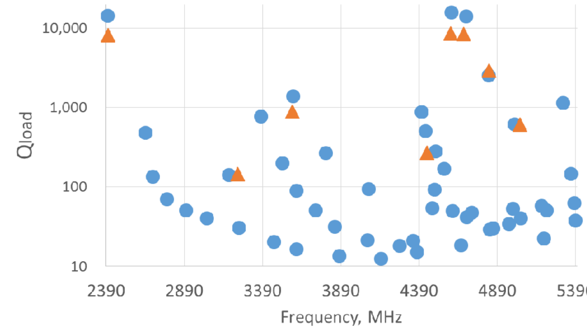

Figure 9: Comparison of CST Q_{load} and measured Q_{load} for the cavity with grooved beam pipe (400 mm). Circles – CST Q_{load}, triangles – measured Q_{load}.

From Figs. 8 and 9 it can be seen that the calculated and measured Q_{load} result to be in a good agreement for the modes that we were able to detect. Other modes have significantly lower values of Q_{load} and cannot be identified. The modes in the region around 4500 MHz are the quadrupole ones with an R/Q values of 10^{-4} and therefore they do not pose any threat for the beam. Q_{ext} for these modes are of the order of 10^4-10^5.

CONCLUSIONS

Thus, the performed measurements have confirmed that there are no dangerous HOM trapped in the cavity with grooves. The presence of some residual HOM detected experimentally and having $Q_{load} < 1000$ is explained by the fact that the prototype was build with the shorting plates at the ends (or using the damping load only from one side) and others are the HOM with R/Q lower than 10^{-4}. This situation is reproduced very well by simulations as seen in Figs. 8 and 9. It is planned to manufacture the second cell of the cavity for measurement of a chain of cavities connected by a drift tube with a small radius.

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