HIGHER ORDER MODES COUPLERS FOR 800 MHZ HARMONIC CAVITY*

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Abstract

For the higher order modes damping (HOM) in the 800 MHz superconducting single cell cavity the HOM coupler was developed. Several versions of the coupler design were shown. For the chain of two cavities with couplers the calculations of external Q-factor are presented. The calculations of multipactor discharge of cavity were also conducted.

INTRODUCTION

High Luminosity Large Hadron Collider (HL-LHC) [1] project considers a possible implementation of harmonic cavities in addition to the main accelerating cavities working at 400 MHz to increase or to shorten bunches. A combination of the existing main RF cavities and harmonic cavities operating at 800 MHz are to be used in order to achieve the desired results. One of the main goals of the design of cavity is to fulfill strict HOM damping requirements.

COUPLER TUNING

An initial design of the harmonic cavity was obtained by scaling (reducing) all the sizes of the LHC accelerating cavities operating at 400 MHz by a factor of 2 (Fig. 1) [2]. Initially it was proposed to provide HOM damping with four couplers: two dipole and two broadband couplers as it was done for 400 MHz accelerating cavity. Several alternatives HOM damping techniques have been investigated [3] and later it was proposed to look into alternative design of HOM couplers [4]. Such a design can possibly help to reduce the number of necessary couplers up to two.

The CST Microwave studio [5] model used for tuning of the couplers is shown in Fig 1.

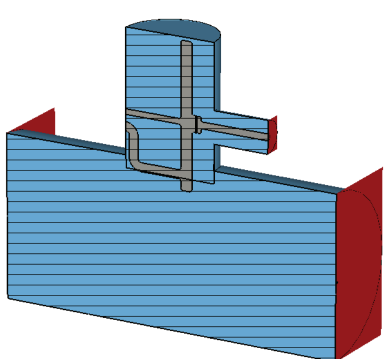

Figure 1: Modes for S-parameter calculations.

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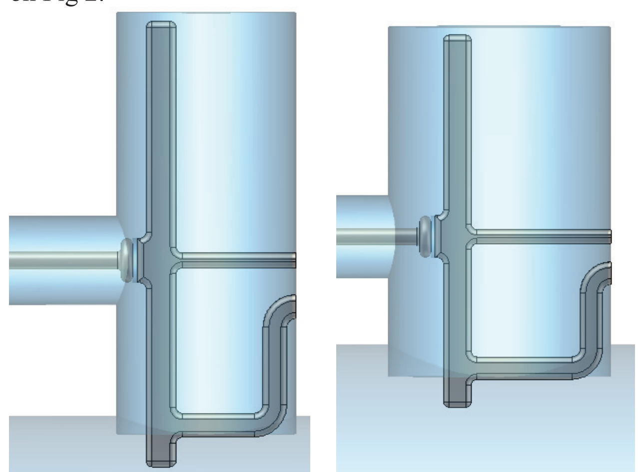
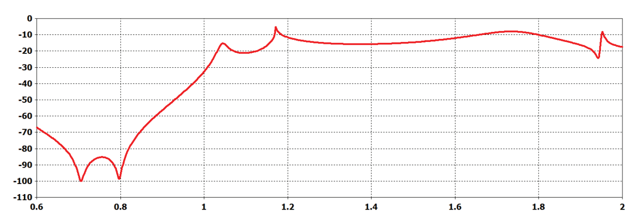
Couplers were tuned for two different radius of coupler pipe of 30 and 40 mm. The tuned couplers are presented on Fig 2.



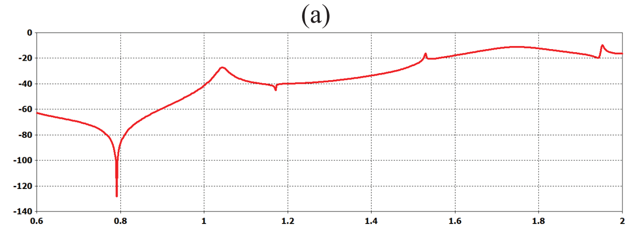
(a) (b)

Figure 2: Tuned couplers with radius of outer conductor of (a) 30 and (b) 40 mm.

The S-parameters for this coupler are presented on a Fig 3.



(a)



(b)

Figure 3: S-parameters for (a) TE_{11} and (b) TM_{01} modes.

In order to check their effectiveness, after the tuning this couplers were added to 2 cell array of cavities (Fig. 4). The calculated Q_{ext} values for the HOM from 1 up to 2 GHz are presented on Fig. 5.

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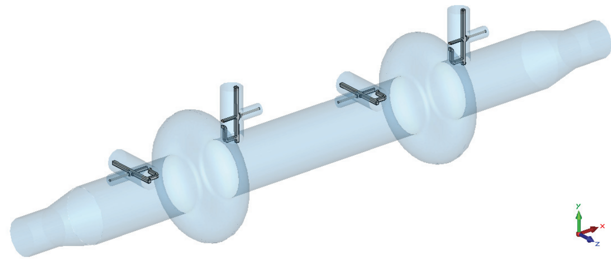


Figure 4: General view of array of two cells and coupler.

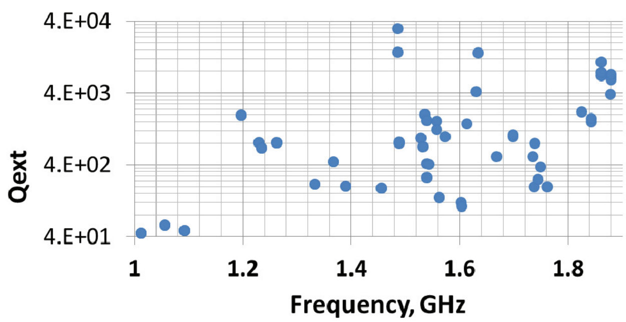
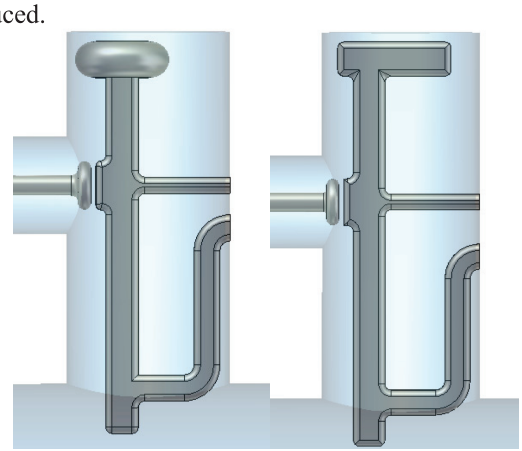


Figure 5: Q_{ext} for an array of two cells with two couplers.

From Fig. 5 we can see that for the dipole modes we achieved quality factor values lower than 100, and lower than 2000 for other HOM except for quadrupole modes at 1450 MHz which have $R_{sh\perp}/Q$ values [6] lower than 10^{-4}, while Q_{ext} of the operational mode TM_{010} above 10^{11}.

SECOND DESIGN

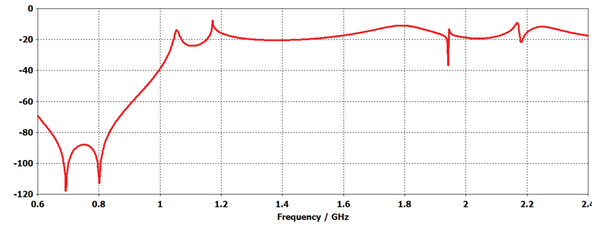
However, despite high HOM damping values couplers in Fig. 2 are quite bulky which may complicate their manufacturing and increase cost of cryomodule. To reduce the outer dimensions of couplers a capacitive element was added at the top (Fig. 6). Two variants of top capacitance were suggested (round and rectangular). While round element can provide higher values of capacitance with smaller volume required, the square one can be easier to manufacture. With additional capacitances we were able to reduce outer conductor radius up to 25 mm. The height of the coupler was also reduced.



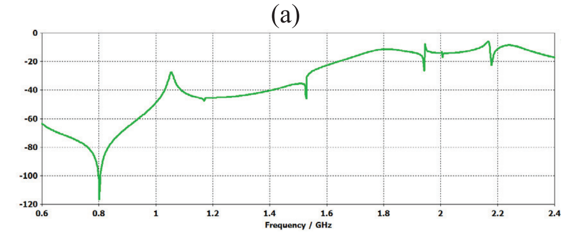
(a) (b)

Figure 6: Tuned couplers with (a) round and (b) square top capacitance.

The S-parameters for this coupler are presented on a Fig. 7.



(a)



(b)

Figure 7: S-parameters for (a) TE11 and (b) TM01 modes.

Q_{ext} values for an array of two cells with two couplers are presented on Fig. 8.

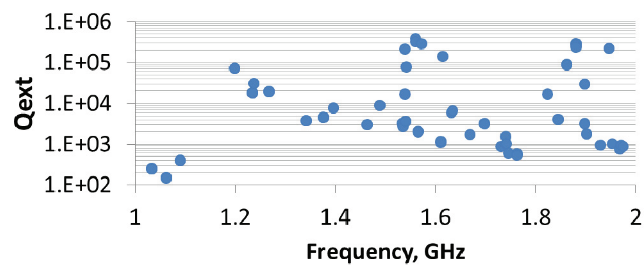


Figure 8: Q_{ext} for an array of two cells with two couplers.

From Fig. 6 we can see that for the dipole modes we achieved quality factor values lower than 300, and lower than 2000 for other HOM except for quadrupole modes at 1450 MHz which have $R_{sh\perp}/Q$ values lower than 10^{-4}.

MULTIPACTOR DISCHARGE

Multipactor discharge (MPD) calculations were made for 800 MHz cavity with 4 different HOM couplers (Fig 2, Fig 6). The estimation of the electric field threshold E_p was made by parallel plates approximation [7].

$$\frac{m\omega^2 d}{\sqrt{4+\pi^2}e} < E_p < \frac{m\omega^2 d}{2e}$$

where e is the electron charge and m the electron mass, and d is the gap between surfaces, ω is the frequency.

The results of calculated threshold values and field levels in the gaps for the coupler Fig 2b are presented in the Table 1. E_p – field strengths diapason in which you may experience multipactor discharge calculated by parallel plate approximation; field strength in the gaps in structure Fig 2b are taken at 1 J stored energy in the cavity; N –field strength normalization coefficients at

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which MPD occurs. Similar calculations were made for all types of structures.

Table 1. Threshold Values and Field Strength in the Gaps for the Coupler Fig 2b.

d, mm	Threshold value E_p, V/m	Field strength in gap, V/m	N Fig.7
1.5	5.81e4 - 1.08e5	2e6	0.029 – 0.054
3	1.16e5 - 2.16e5	1.055e6	0.1 – 0.2
12	4.65e5 - 8.65e5	1.25e5 - 3.75e5	1.2 - 6.9
20	7.75e5 - 1.44e6	0.5e5 – 2e5	3.873 – 28
34	1.51e6 - 2.81e6	0.5e5 – 3e5	5 – 56

800 MHz harmonic cavity works at 10 MV/m accelerating gradient (accelerating voltage 2 MV per cavity) which corresponds to the normalization coefficients of 3. From Table 1 it can be seen that field strength in 1.5 and 3 mm gaps are significantly lower than operation level of fundamental mode. The most dangerous from this point of view is 12 mm gap. The threshold values for 20 and 34 mm gaps are higher than operational level.

For a detailed study of the electron trajectories stability the multipactor discharge simulations were performed in three-dimensional modeling program MultP-M [8]. Fig.8 shows the obtained Phase/Field diagrams for the four types of HOM couplers. Phase/Field diagrams shows the levels of field and emission electron phase with respect to RF field normalization coefficient at which trajectories are saved for 10 RF periods.

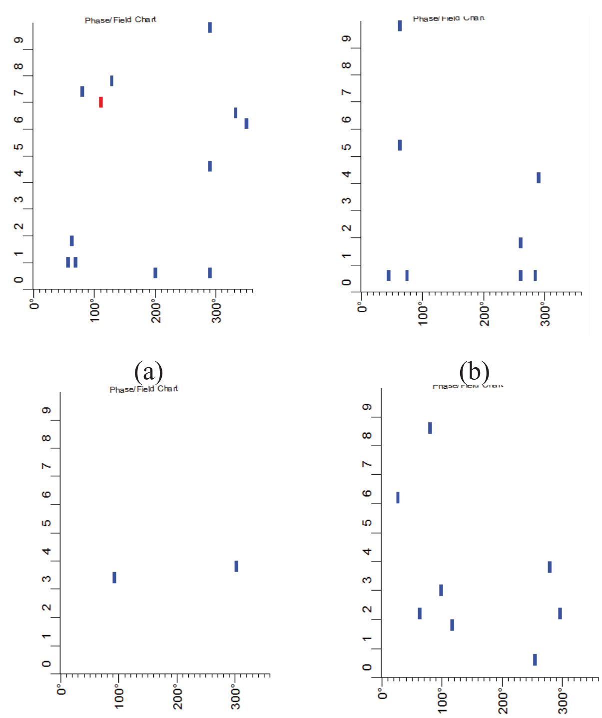

Figure 8: Phase/Field diagrams for different construction: (a) radius of coupler pipe of 30 mm; (b) radius of coupler pipe of 40 mm; (c) rectangular top capacitance; (d) round top capacitance.

From the chart it can be seen that the best results were achieved for the structures with couplers 2a and 2b. The results of study of the electron trajectories show that the trajectories in the equatorial region of the resonator (typical for elliptical cavities) are observed at N=2.5 and lower which is lower than the operating field level. Trajectories in the 1.5 and 3 mm gaps at the operating level are not found. At energies below the operating level trajectories were found in the cavity equator region and in the 10 mm gap. At levels above the operating level, the trajectories are concentrated in the HOM couplers. For the couplers 6a and 6b trajectories are found both in lower and in top parts of the couplers.

CONCLUSION

The possibility HOM damping in the chain of two cavities with two HOM couplers per cell was investigated. It was shown that the quality factor values of the dipole modes lower than 300 and lower than 2000 was achieved.

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