ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMN047

SUPPRESSION OF HIGHER ORDER MODES IN AN ARRAY OF CAVITIES USING WAVEGUIDES*

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Abstract

In the frameworks of the High Luminosity LHC upgrade program an application of additional harmonic cavities operating at multiplies of the main RF system frequency of 400 MHz is currently under discussion. A structure consisting of two 800 MHz single cell superconducting cavities with grooved beam pipes coupled by drift tubes has been suggested for implementation. However, it is desirable to increase the number of single cells installed in one cryomodule in order to decrease the number of transitions between "warm" and "cold" parts of the collider vacuum chamber. Unfortunately it can lead to the appearance of higher order modes (HOM) trapped between the cavities. In order to solve this problem the methods of HOM damping with rectangular waveguides connected to the drift tubes were investigated and compared. In this paper we describe the results obtained for arrays of 2, 4 and 8 cavities.

INTRODUCTION

The Large Hadron Collider luminosity upgrade (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. In order to achieve the desired results a combination of the existing main RF cavities and harmonic cavities operating at 800 MHz is being studied. One of the main goals of the design of cavity is to fulfill strict HOM damping requirements. Several techniques for HOM damping such as beam pipe grooves, fluted beam pipes, ridged beam pipes etc. have been suggested, investigated and compared.

It is desirable to combine more cavities in a single cryostat in order to avoid multiple transitions between cryogenic and "warm" areas. However, connecting several cavities in a chain can create parasitic HOM that may affect the stability of circulating beams and lead to excessive power loss. The methods of HOM damping with rectangular and ridged waveguides attached to the beam pipes, usage of fluted and ridged beam pipes, as well as combinations of these methods have been considered and compared in order to solve this problem.

*Work is supported by Ministry of Education and Science grant 3.245.2014/г и and by the EU FP7 HiLumi LHC - Grant Agreement 284404.

SINGLE CELL

An initial design of the harmonic cavity was obtained by scaling (reducing) all the sizes of the LHC accelerating cavity operating at 400 MHz by a factor of 2 (Fig. 1) [2]. HOM damping is carried out with four couplers: two dipole and two broadband couplers. Unfortunately those couplers have some drawbacks including: violation of the cylindrical symmetry of the electromagnetic field in the structure which gives rise to the transverse component of the electric field (kick-factor), the complexity of the installation of robust power coupler on the same pipe with HOM couplers and possibility of multipacting discharges. That's why several alternatives HOM damping techniques have been investigated (Fig 2-4) [3].

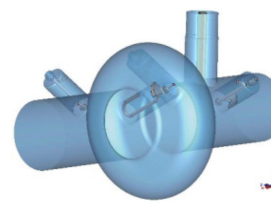

Figure 1: Accelerating cavity.

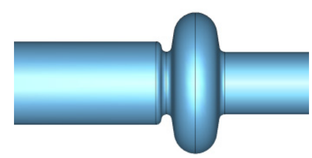

Figure 2: Cavity with grooved beam pipes.

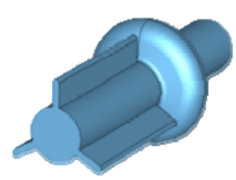

Figure 3: Structure with 3 flutes.

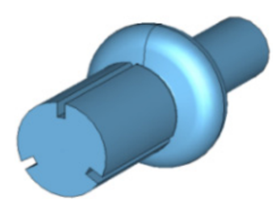

Figure 4: Structure with ridged beam pipe.

The frequency of dipole HOMs lies below the cut-off frequency of the TE_{11} wave and therefore cannot propagate along the drift tube in the structure shown in Fig. 1. The main feature of structures from Fig. 2-4 is that the HOMs frequencies become lower than the beam pipe cut-off frequency which allows [4] providing damping with a load placed in the drift tube outside the cryomodule. The results of wakefield simulations conducted with ABCI code [5] and CST [6] has clearly demonstrated that in these structures we managed to obtain a truly "single mode" cavity. We should not expect multibunch instabilities since the wake field decays completely at the distance of 15-25 m that corresponds to the actual bunch separation of 50 ns in LHC. The results obtained for single cell structures with grooved, fluted and ridged beam pipes are similar. In all the structures Q_{ext} are below 100 for all HOMs (except for a few modes

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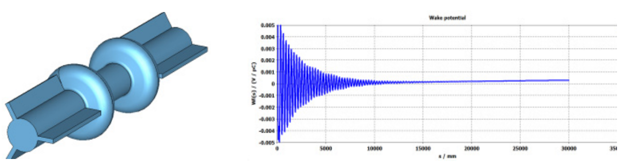
with low R/Q ratio) resulting in a very fast wake field decay. That is why we have also proposed to combine two such cavities connected by smaller radius beam pipe in a single cryostat [2].

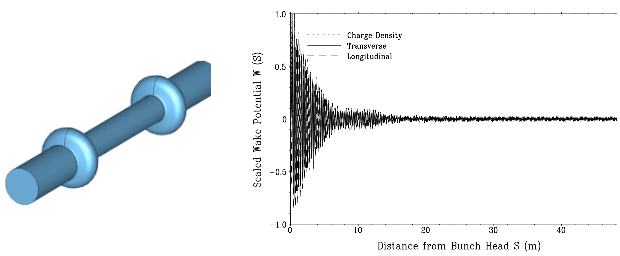
ARRAY OF TWO CELLS

The arrays of two cells with fluted beam pipes and grooved beam pipes connected by the drift tube are presented in Fig. 5a and 6a.



a b

Figure 5: a) Array of 2 cells with fluted beam pipe; b) transverse wake potential.



a b

Figure 6: a) Array of 2 cells with grooved beam pipe; b) transverse wake potential.

Figures 5b and 6b shows that the transverse wake potential for these structures falls almost to zero at a distance comparable to the bunch separation in LHC. The high decay rate could be achieved due to the low cut-off frequencies of H_{11} and H_{21} waves in the fluted beam pipe. Nevertheless, E_{01} cut off frequency is high enough to keep operating mode trapped in cavity preventing its dissipation in the load.

In our opinion, the solution with grooves is preferable due to its cylindrical symmetry, design simplicity and absence of dangerous HOMs.

HOM DAMPING WITH WAVEGUIDES

We can conclude that in an array of two cavities HOM damping is not a problem. But if we want to increase the number of cells we will face a problem of damping of parasitic modes trapped in a drift tube between the cells (see Fig. 7, as an example).

Extraction of the trapped modes power could be obtained with waveguides attached to the connecting drift tubes (Fig. 8a). A solution with "wings" has proven to be effective in extraction of fields propagating along the beam pipes [7]. At a certain length of the connecting drift tube and the waveguide the fast decay of the wake potential is provided (Fig. 8b) and, respectively, the absence of sharp peaks in the graph of the transverse impedance is observed (Fig. 8c). However, the longitudinal impedance exhibits several peaks that can be potentially dangerous (Fig 8d). These peaks correspond to the monopole HOMs. The extraction of this HOMs is complicated by the fact that the wave that they excite in the waveguide does not propagate through, since the cut-off frequency of this wave is much higher than the frequency of these HOM.

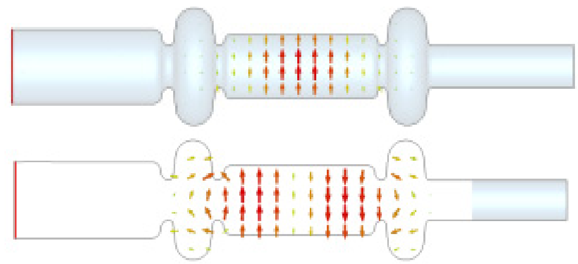


Figure 7: Distribution of electric field of trapped modes.

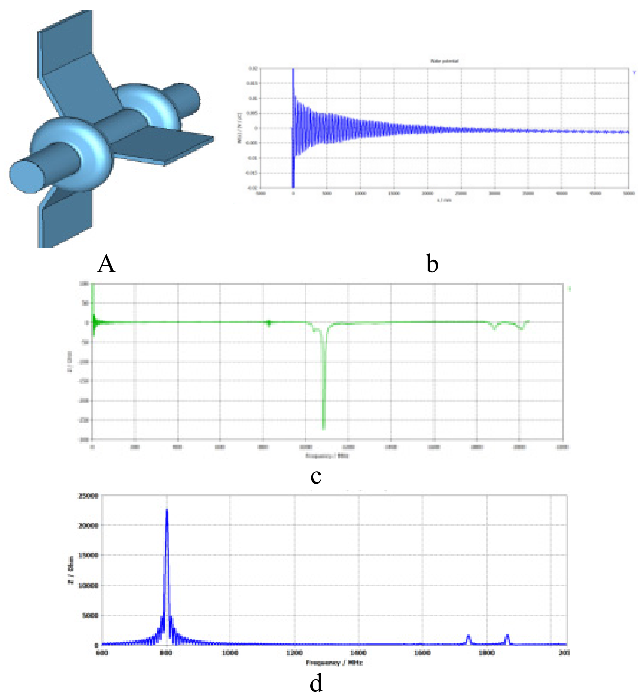


Figure 8: a) Array of 2 cells with attached waveguide; b) transverse wake potential; c) transverse impedance; d) longitudinal impedance.

In order to provide conditions for monopole modes damping the waveguides with increased height were attached to the structures with the ridged beam pipe (Fig. 9a). A number and amplitudes of peaks on longitudinal impedance graph was decreased (Fig 9b).

Unfortunately, application of such large waveguide structures could break the cylindrical symmetry of the operating mode; lead to an excitation of the transverse potential and could be difficult in manufacturing. So it was decided to add "teeth" to these waveguides (Fig 10a) that decrease the cut-off frequency for the monopole and other HOMs. This will allow us to decrease sizes of the waveguides.

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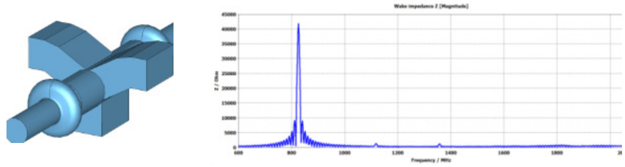
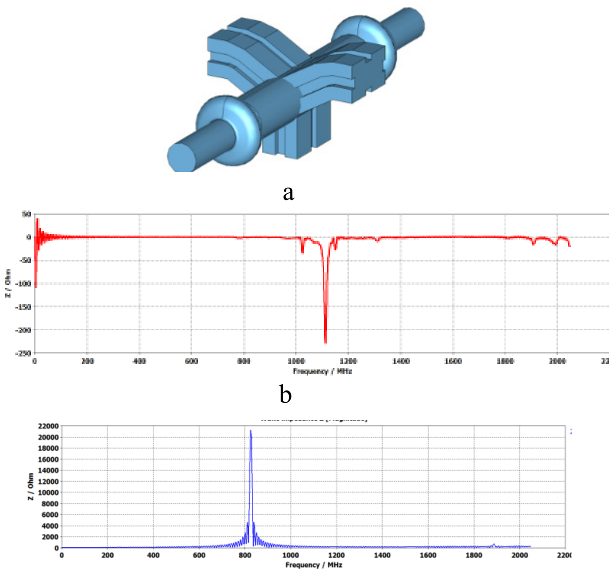


Figure 9: a) Array of 2 cells with attached wide waveguide; b) longitudinal impedance.



a

b

c

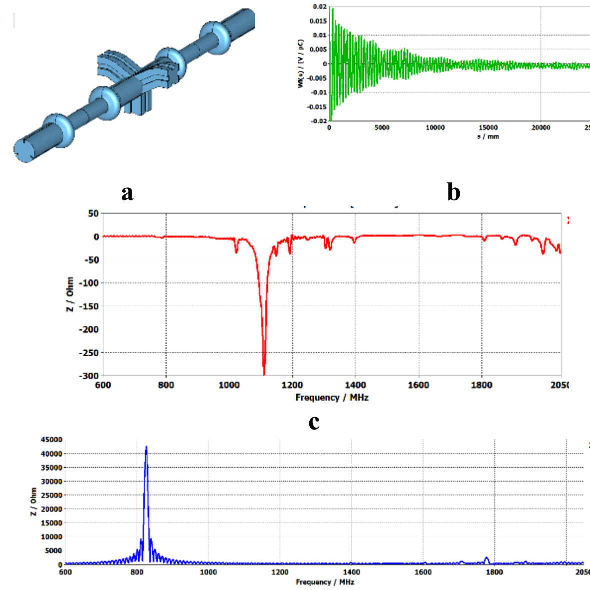
Figure 10: a) array of 2 cells with ridged waveguides; b) transverse impedance; c) longitudinal impedance.

In such a structure, the fast wake decay was achieved, the absence of sharp peaks was obtained for both the transverse (Fig. 10b) and the longitudinal (Fig. 10c) impedance. The same calculations have been performed for the array of 4 cells (Fig 11a).

The wake potential decays reasonably fast (Fig 11b) and the transverse and longitudinal impedances (Fig 11c, 11d) do not reveal strong HOMs. For the array of 6 and 8 cavities the dependences shows similar behaviour.

CONCLUSIONS

The simulation results and the following analyses show that all options with two cavities connected by the drift tube have no problems with HOM damping. In turn, the HOM damping in arrays of 4 cavities could also be efficient with the help of additional waveguides.



a b

c

d

Figure 11: a) Array of 4 cells with ridged waveguide; b) transverse wake potential; c) transverse impedance; d) longitudinal impedance.

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