COMPARSION OF HIGHER ORDER MODES DAMPING TECHNIQUES FOR AN ARRAY OF SINGLE CELL CAVITIES

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Abstract

The LHC High Luminosity upgrade program considers an option of using additional cavities, operating at multiplies of the main RF system frequency of 400 MHz. Such harmonic cavities should provide a possibility to vary the length of colliding bunches. In order to supply the required harmonic voltage several single cell superconducting cavities are to be used. It is desirable to house more cavities in a single cryostat to reduce the number of transitions between "warm" and "cold" parts of the cryogenic system. In this paper we study electromagnetic characteristics of a chain of the single cell superconducting cavities coupled by drifts tubes. In order to reduce the influence of Higher order modes (HOM) excited in the structure on the beam stability and to minimize eventual power losses we analyze the HOM parameters and calculate the wake potential decay rates due to application of different HOM damping devices. In particular, the methods of HOM damping with rectangular waveguides connected to the drift tubes, the loads placed in the fluted and ridged drift tubes, as well as combinations of these methods are compared.

INTRODUCTION

In the frameworks of High Luminosity LHC upgrade [1] an application of additional second harmonic cavities with the operating frequency of 800 MHz is currently under discussion. It is desired to combine more such 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 higher order modes (HOM) that may affect the stability of circulating beams and lead to excessive power loss. In order to reduce the influence of HOM excited in the structure by passing beams their electromagnetic characteristics were calculated and the decay rates of the induced wake potential in the chain of cavities with different HOM damping devices were analyzed. In particular, 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 were considered and compared.

ARRAY OF TWO CELLS

HOM extraction from superconducting cavities could be realised in different ways. The most common HOM damping technique is the HOM extraction with couplers. These devices are effective but they also have some disadvantages. They break the cylindrical symmetry of operating mode leading to appearance of the transverse potential (kick-factor); they are subjects to all kinds of pollutions and multipactor discharge [2]. Another method implies HOM extraction to the load placed outside of a cryogenic system. The load can be made of ferrites or in a form of resistive material on an inner surface of the drift tube. In this case, it is necessary to have frequencies of these HOM higher than cut-off frequencies of drift tube in order to provide conditions for HOM propagation toward the load.

In [3, 4] HOM damping technique for the structure with fluted beam pipe was considered. Such beam pipe provides conditions for HOM propagation toward the load. In this structure a high speed of wake field decay was observed that is why it was decided to consider the option of a chain of two such resonators (Fig 1a).

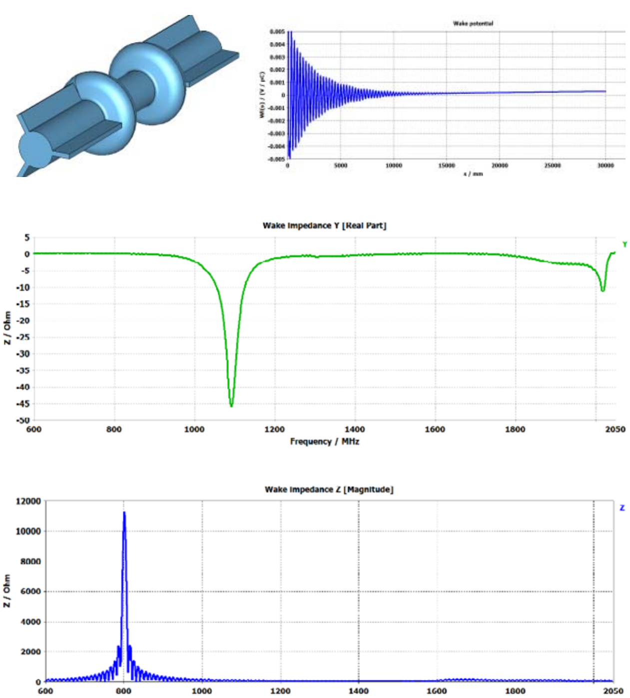

Figure 1: a). Array of 2 cells with fluted beam pipe; b). Dipole wakefield; c). Transverse impedance; d). Longidtudinal impedance.

Fig 1b shows that the wake potential falls almost to zero at a distance comparable to the bunch separation in LHC. The high decay rate could be achieved due to the

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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 [3, 4] the HOM damping technique for the structure with ridged beam pipe was also considered. Such beam pipe also provides conditions for HOM propagation toward the load. In this structure a high speed of wake field decay was observed so that it was decided to conduct the same calculations (Fig 2a) as for the 2 cell array of structure with fluted beam pipe.

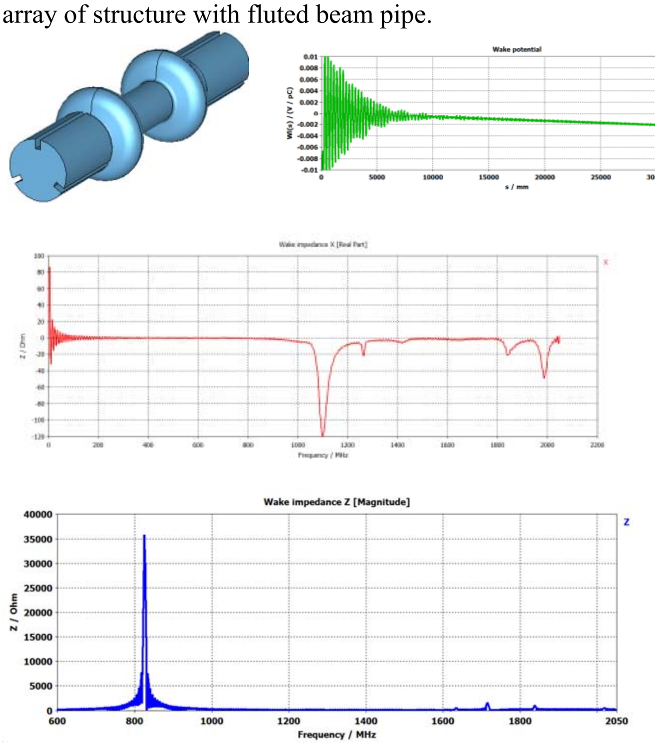

Figure 2: a). Array of 2 cells with ridged beam pipe; b). Wake potential; c). Transverse impedance; d). Longitudinal impedance.

From Fig. 2b it is seen that the wake potential decays very fast. Respectively, there also no sharp peaks corresponding to HOM with Q_{ext} higher than 100 on the graph of the transverse impedance (Fig. 2c) and longitudinal impedance (Fig. 2d)

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 modes trapped between the cells in a drift tube. So we have to study methods to suppress these modes. HOM extraction of the trapped modes could be obtained with waveguides attached to the connecting drift tubes (Fig. 3a). Such a solution with "wings" has proven to be effective in extraction of fields propagating along the beam pipes [5]. At a certain length of the connecting drift tube and the waveguide the high rate of decay of the wake potential is provided (Fig. 3b) and the absence of sharp peaks in the graph of the transverse impedance is observed (Fig. 3c). However, the longitudinal impedance exhibits several peaks that can be potentially dangerous. These peaks correspond to the monopole HOM. The extraction of this HOM 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.

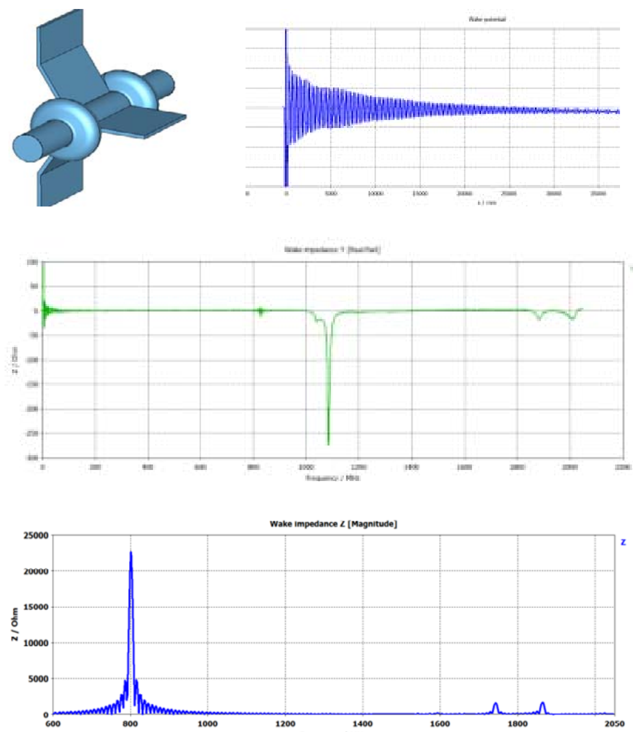

Figure 3: a). Array of 2 cells with attached waveguide; b). Wake potential; c). Transverse potential; d). Longitudinal impedance.

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. 4a). A number and amplitude of peaks on longitudinal impedance graph decreased (Fig 4b).

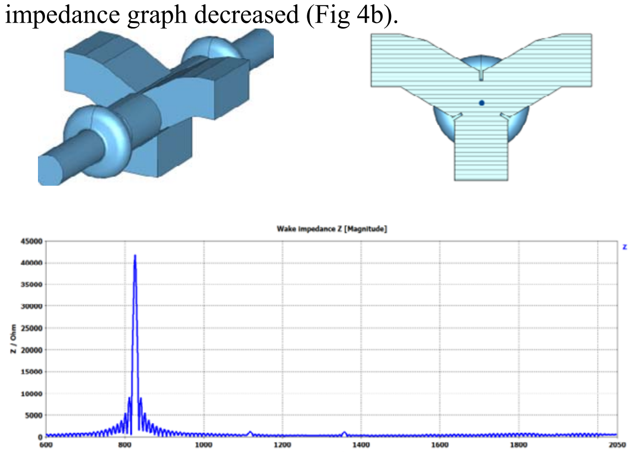

Figure 4: Array of 2 cells with attached wide waveguide and Longitudinal impedance.

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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. That is why it was decided to add "teeth" to these waveguides (Fig 5a) that decrease the cut-off frequency for the monopole and other HOMs. This will allow us to decrease sizes of the waveguides.

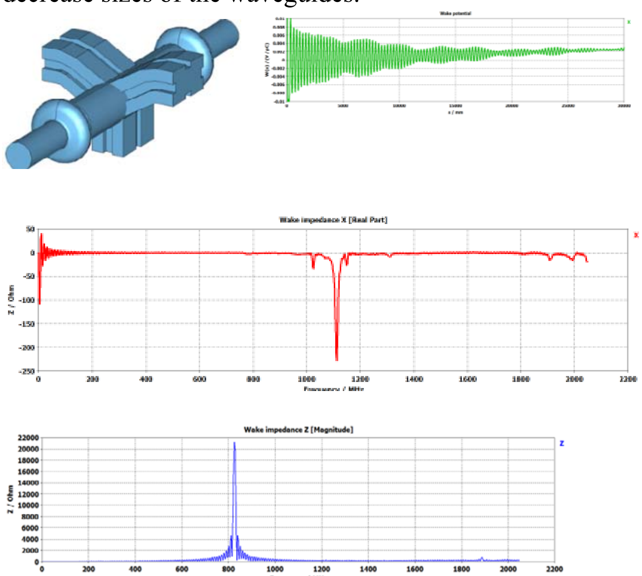

Figure 5: a). Array of 2 cells with ridged waveguides; b). Wake potential; c). Transverse potential; d). Longitudinal impedance.

In such a structure, the fast wake decay was achieved (Fig. 5b). The absence of sharp peaks was obtained for both the transverse (Fig. 5c) and the longitudinal (Fig. 5d) impedance.

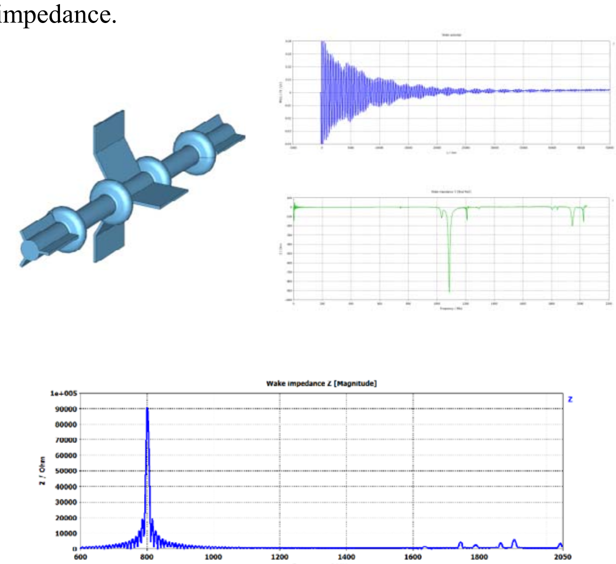

Figure 6: a). Array of 4 cells with waveguides; b). Wake potential; c). Transverse impedance; d). Longitudinal impedance.

4 CELL ARRAY

As long as the structures shown in Fig 1a and Fig 3a have demonstrated good results the calculations for an array of four cells (Fig 6a) have been conducted. As expected, the wake potential decays reasonably fast (Fig 6b) and the transverse and longitudinal impedances (Fig 6c, 6d) do not reveal strong HOMs. For the array of 6 and 8 cavities the dependences shows similar behaviour.

The same calculations have been performed for the combination of structures shown in Fig 2a and 5a. The obtained results are presented in Fig 7a.

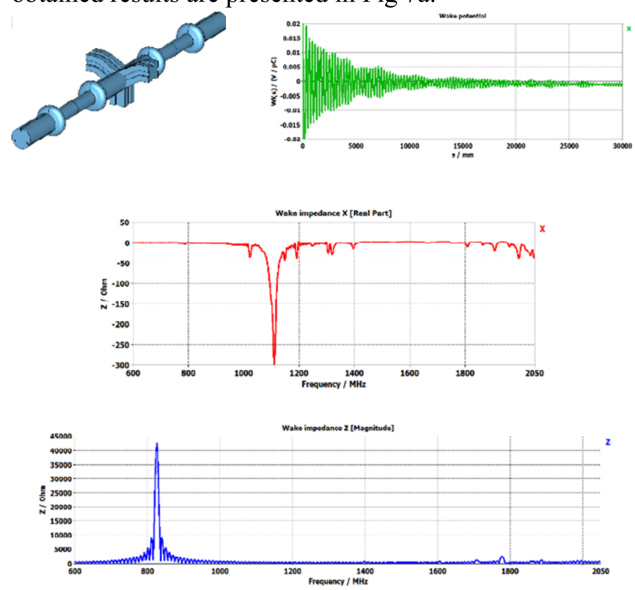

Figure 7: a). Array of 4 cells with ridged waveguide; b). Wakepotential; c). Transverse impedance; d). Longitudinal impedance.

The results (Fig 7b-7d) are the similar to those for the structure in Fig 5a.

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 waveguides.

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