COMPASSION OF HIGHER ORDER MODES DAMPING TECHNIQUES FOR SUPERCONDUCTING 9-CELL STRUCTURE
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Abstract
Modern types of accelerators, such as Energy recovery linacs, require low values of higher order modes (HOM) Q<sub>ext</sub>. In accelerators with high current HOM could lead to high losses for the modes excitation, beam instability and beam break up. HOM couplers and waveguides are often used in such structures for HOM damping. Unfortunately they could lead to a violation of the axial symmetry of the accelerating field and negatively affect the beam emittance. Also these devices are subject for multipactor discharge and could be difficult in maintaining and fabrication. In this paper we examine several ways of HOM damping with ridged, fluted and corrugated drift tubes which are devoid of the above-mentioned drawbacks. The influence of the parameters of the drift tube on the HOM damping and on the parameters of the fundamental wave were analyzed.

INITIAL DESIGN
As a reference point for simulations 9-cell 1300 MHz superconducting accelerating cavity (Fig. 1a) [1] was analyzed. In order to estimate efficiency of HOM damping in such structure electrodynamic characteristics (EDC) [2] were calculated for the structure without couplers but with ideal load boundary conditions at the end of drift tubes. EDC of operating mode presented in Table 1.

In order to estimate HOM frequency range dispersion characteristics (Fig. 1b) for TM<sub>010</sub> modes and HOMs were plotted. The most dangerous HOMs for the structure are dipole modes TE<sub>111</sub>, TM<sub>110</sub>; quadrupole modes TE<sub>211</sub> and TM<sub>210</sub> and monopole mode TM<sub>011</sub>. Line β<sub>phase</sub> = 1 is also presented on the graph. Intersection points of dispersion characteristics with β<sub>phase</sub> = 1 line (synchronous point) represent modes with the highest interaction between particles and modes and requires additional attention. External Q-factor Q<sub>ext</sub> and shunt impedance R<sub>sh</sub> for HOMs and operational mode presented on the Fig 2 and 3. Q<sub>ext</sub> values were calculated in CST Microwave Studio [3].

Comparison of the results with similar structures [4] showed that Q<sub>ext</sub> for operating mode is nearly the same, for dipole modes it is three orders higher, 4-5 orders higher for quadrupole modes and for 2nd monopole HOM its two times higher.

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FLUTED, RIDGED AND CORRUGATED BEAM PIPE

Simulation of 9-cell structures with fluted, ridged and corrugated beam pipes were performed. Previously these designs were successfully applied for HOMs damping in single cell cavities [5]. EDC of operating mode for these structures are presented in Table 1.

Fluted beam pipes are presented on Fig. 4a. Number and form of those flutes can be chosen on purpose to achieve higher values of HOMs damping. The best results for damping of dipole and quadrupole HOMs were obtained for a structure with fluted beam pipes with 3 flutes [5,6]. The structure with 4 flutes had problems with quadrupole HOMs damping with certain polarization.

Figure 4. 9-cell cavity with a) fluted beam pipe; b) ridged beam pipe; c) corrugated beam pipe.

Figure 5. Q_{ext} for HOMs in 9-cell elliptical cavity with a) fluted beam pipes; b) ridged beam pipes; c) corrugated beam pipes. Square – monopole waves, circle – dipole waves, diamonds – quadrupole waves.

Figure 6. R_{sh} for 9-cell elliptical structure with a) fluted beam pipes; b) ridged beam pipes; c) corrugated beam pipes. Square – monopole waves, circle – dipole waves, diamonds – quadrupole waves.

The main advantage of fluted beam pipe is that H_{21} cut-off frequency is below of the quadrupole HOMs band. This is true not only for quadrupole but also for dipole HOMs. The operational mode remains trapped in the structure due to high cut-off frequency of TM_{01} mode. Cut-off frequency values for modes TE_{11}, TM_{01}, TM_{21} in fluted beam pipe are respectively 1330, 1972 and 2004 MHz.

In order to get the same cut-off frequency cylindrical beam pipe beam pipe radius should be 65.5 mm for TE_{11} wave and 72.8 mm for TE_{21}, however it will cause reduction for TM_{01} cut-off frequency (on 248MHz and 396MHz correspondingly). It could create to negative effect for shunt impedance of operating mode.

<table>
<thead>
<tr>
<th></th>
<th>Cylindrical</th>
<th>Fluted</th>
<th>Ridged</th>
<th>Corrugated</th>
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<td>R_{sh}/Q_{ext}, Ohm</td>
<td>980</td>
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<td>951.9</td>
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Table 1. EDC of operating mode TM_{010} for structures with different beam pipes (f=1300 MHz)

Comparing Q_{ext} (Fig 5a) and R_{sh} (6a) results for the 9-cell structure with fluted (Fig. 4a) and for cylindrical beam pipes (Fig. 1a) and results obtained for the similar structures [4], we can conclude that this method is very effective because of we see reduction of Q_{ext} values were
reduced by two orders of magnitude monopole and dipole and by five orders for quadrupole HOMs.

Another structure that provides conditions for HOMs propagation is ridged beam pipe structure (Fig. 4b). The ridged beam pipe geometry is symmetrically opposed to fluted beam pipe. Typically it has 3 grooves in beam pipe, evenly distributed on azimuth on 120° angle. EDC of operating mode presented in Table 1.

Results for $Q_{ext}$ and $R_{sh}$ in 9-cell structure with ridged beam pipes are presented on Fig 5b and 6b.

We found that the results for ridged beam pipe are even better than for fluted beam pipe. All the dipole and monopole modes have $Q_{ext}$ values lower than $10^4$, quadrupole modes lower than $10^3$.

The last design to check was structure with corrugated beam pipe (Fig. 4c). From the results of $Q_{ext}$ and $R_{sh}$ presented on Fig 5c and 6c are very close to achieved for structures with fluted and ridged beam pipes.

**CONCLUSIONS**

Propagation of HOMs from 9-cell structure was compared for cylindrical, fluted and ridged beam pipes. The comparison has been done based on calculated external quality factor $Q_{ext}$ and $R_{sh}$ in the models with beam pipes loaded with RF ports at the ends. In the result the fluted and ridged beam pipes showed $R_{sh}$ for HOMs 3 orders of magnitude lower than for structure from Figure 1a. We are planning to precede development of HOM dampers for 9-cell structure based on this result.

**REFERENCES**