ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB052

HIGHER ORDER MODES DAMPING IN 9-CELL SUPERCONDUCTING CAVITY WITH GROOVED BEAM PIPE*

A. M. Bulygin, R. Donetskiy, Ya.V. Shashkov
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia

Abstract

This paper is focused on higher order modes (HOM) damping efficiency analysis in 9-cell superconducting cavities with HOM couplers and with grooved beam pipe. Comparison of two methods of HOM damping is presented. In order to increase efficiency of damping of trapped modes the end cells of the structure were modified.

HIGHER ORDER MODES

A large number of modes in a broad frequency range are induced by the beam passing through the structure [1]. The on-axis movement of the bunch leads to the appearance of monopole modes, off-axis bunch also excites multipole HOM (dipole, quadrupole, etc).

HOM leads to a number of negative factors: energy losses, beam deflection from axis, additional heat load on cryogenics, beam break up etc.

Electrodynamic characteristics (EDC), such as external Q-factor (Q_{ext}) and shunt impedance R_{sh} are used to evaluate the HOMs impact on bunch. Transverse shunt impedance to the Q-factor ratio can be calculated either through Panofsky-Wenzel theorem:

$$\frac{R_{sh\perp}}{Q} = \frac{|\int_0^l \frac{1}{k_z}\frac{\partial E_z}{\partial r} e^{ik_z z} dz|^2}{\omega W} \quad (1)$$

where W-stored energy, k_z-wave number; or using direct integration of transverse magnetic H and electric fields:

$$\frac{R_{sh\perp}}{Q} = \frac{|\int_0^l (i \cdot c \cdot \mu_0 \cdot H_\perp(z) + E_\perp(z)) e^{ik_z z} dz|^2}{\omega W} \quad (2)$$

For axially symmetric structures longitudinal field derivative in (1) can be replaced by the difference, and given that the longitudinal field dipole waves on the structure axis are zero, the resulting expression will look like this:

$$\frac{R_{sh\perp}}{Q} = \frac{|\int_0^l \frac{1}{k_z}\frac{E_Z(r=l)(z)}{\Delta r} e^{ik_z z} dz|^2}{\omega W} \quad (3)$$

In order to decrease their influence on the travelling bunch it is necessary to decrease the HOM Q-factor values. The most common method for HOM damping in accelerating structure involves the coaxial couplers which extracts HOM power to the external load. Despite the fact that couplers provide a reasonable HOM damping they are often of complicated design and could be subject to multipacting discharge. Their presence also leads to break of accelerating structure axial symmetry. Kick momentum to the beam could be crucial for electron linear colliders, energy recovery linacs and particle accelerators with high beam current.

The resent progress allows applying complex geometries of superconducting cavities to minimize the effect of the HOMs [1-3]. Despite the very low achieved Q-values of HOM their complex geometry can increase the cost of cavity production. Several modifications of simple structure with grooved beam pipe were investigated in order to achieve the lowest values of HOM Q-factor.

9-CELL CAVITIES WITH CYLLINDRICAL BEAM PIPES

In order to increase the HOM damping efficiency of trapped modes in [4] the different radiuses of end cells were used (Fig. 1(a)). This allowed increasing beam's energy to 80-100 MeV. For the 9-cell cavity with cylindrical beam pipes the field distribution for operational mode at 1300 MHz was flattened by the modification of the end-cells (Fig. 1(b)).

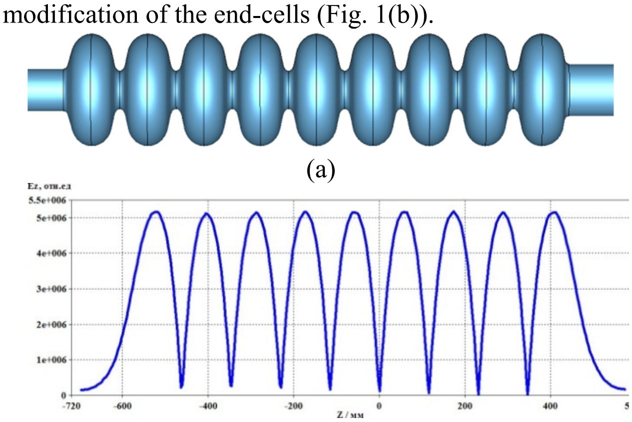


Figure 1: (a) Model of 9-cell cavity with cylindrical beam pipes and (b) electric field distribution for operational mode.

HOM EDCs were calculated for the 9-cell cavity with cylindrical beam pipes in frequency range up to 3 GHz. Dispersion curves (Fig. 2) helped to determine the most dangerous HOMs.

The monopole mode TM_{011}, dipole modes TE_{111}, TM_{110} and quadrupole modes TE_{211} and TM_{210} (Fig. 3) are of the most concern for this structure. The EH_{111} mode is the most "dangerous", because its frequency (2576 MHz) is nearly the double accelerating frequency (1300 MHz). It means that EH_{111} can greatly impact on beam.

* This project is supported in part by the MEPhI 5/100 Program of the Russian Academic Excellence Project

18th International Conference on RF Superconductivity SRF2017, Lanzhou, China JACoW Publishing
ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB052

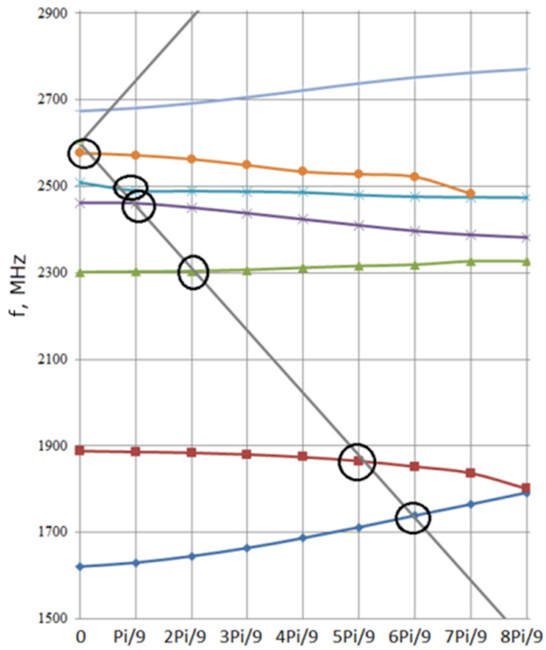


Figure 2: Dispersion characteristics.

9-CELL CAVITY WITH HOM COUPLERS

The variation of Tesla-type coupler [5] was used in order to estimate the values that could be achieved with this damping methodic (Fig. 3 (a)). Couplers are located at cylindrical beam pipes of 9-cell 1300 MHz superconducting accelerating cavity (Fig. 3(b)) at 115^0 degree between each other.

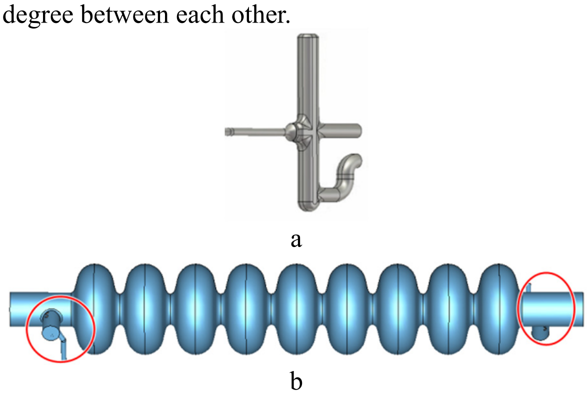


Figure 3: Tesla type HOM coupler (a), 9-cell cavity HOM couplers (b)

Comparison of the results for 9-cell cavity with HOM couplers (Fig. 3 (b)) with 9-cell cavity with cylindrical beam pipes (Fig. 1(a)), showed that Q_{ext} values for TE_{111} and TM_{110} and TM_{011} modes are 100 times higher, 3 orders higher for quadrupole modes, and for EH_{111} is nearly the same (Fig. 4 (a)). R_{sh} values for 9-cell cavity with cylindrical beam pipes 10 times higher for dipole modes and E_{020} wave, 2-3 orders higher for quadrupole waves and E_{011} wave. All the monopole dipole and quadrupole modes of 9-cell cavity with HOMs have R_{sh} values lower than 10^6 Ohm, except H_{211} wave (Fig. 4 (b), (c)).

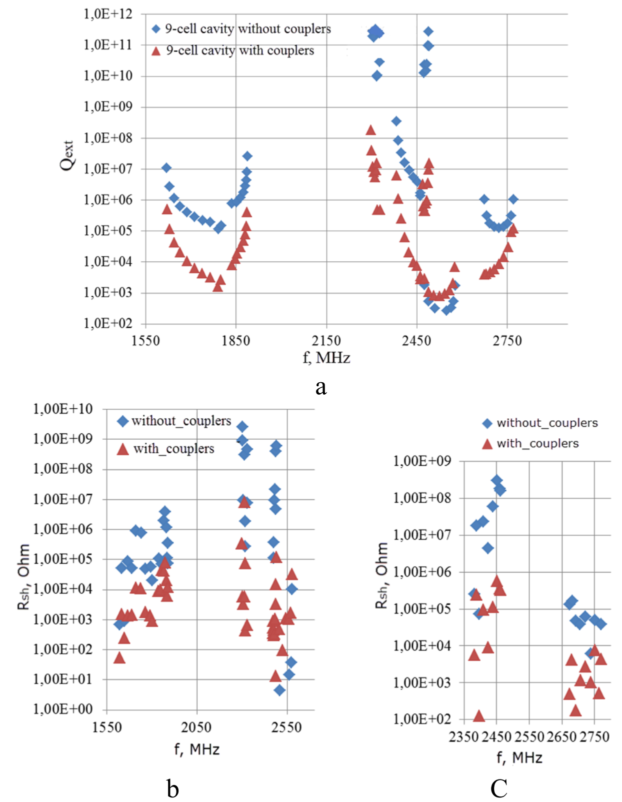


Figure 4: Q_{ext} (a), transverse shunt impedance $R\perp$ (b), longitudinal shunt impedance $R_{\|}$ (c), for HOMs in 9-cell cavity without HOM couplers and 9-cell cavity with cylindrical beam pipes and HOMs couplers.

9-CELL CAVITY WITH CORRUGATED BEAM PIPES

We are considering corrugated beam pipes for three different beam pipe radius dr1: 39, 48 and 56.5mm (Fig. 5) from each side.

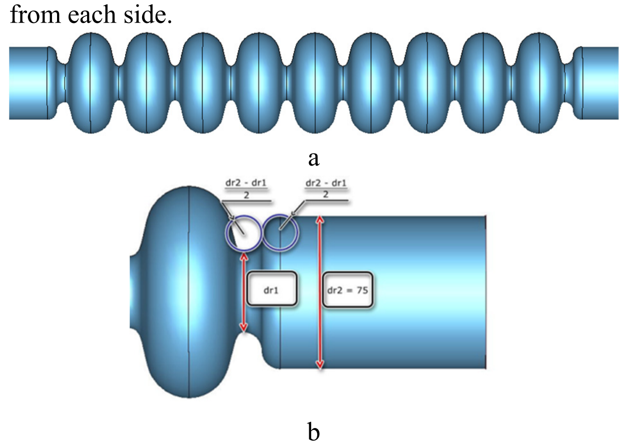
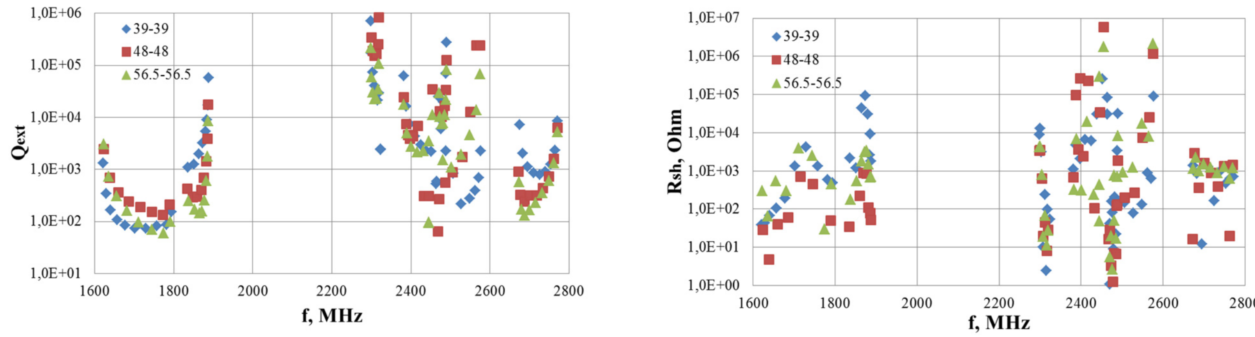


Figure 5: Nine-cell cavity with corrugated beam pipe (a), corrugated beam pipe geometry (b)

We consider 6 types of cavities with different drift tube radius. Three types are demonstrated the best results in HOM damping (Fig. 6).

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB052



a b

Figure 6: Q_{ext} (a), shunt impedance R_{sh} (b) for HOM′s in 3 types of 9-cell cavity with corrugated beam pipe and different external radius dr1 (39, 48 and 56.5 mm)Results of EDC of three types of cavities with different radius dr1 comparison are summarized in Table 1.

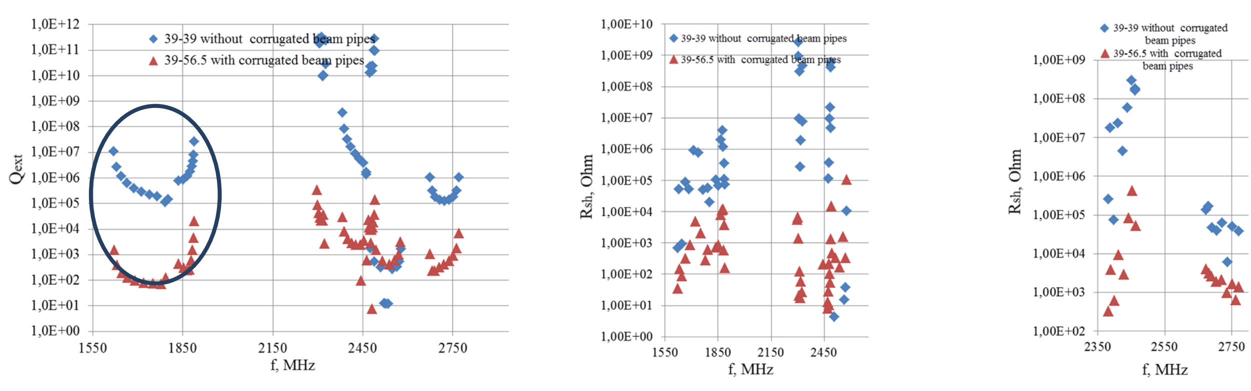
Table 1: Comparison of 9 Cell Structure with Different Radius of Beam Pipe of End Cells

dr1-dr2	39-39	56.5-56.5
Pros	Best results for damping of TE_{111}, TM_{011}, EH_{111} waves.	Best results for damping of TM_{110}, TE_{211}, TM_{020} waves.
Cons	Worst results for damping of TM_{110}, TE_{211} и TM_{210} waves.	Worst results for damping of EH_{111} wave. R_{sh} of several HOM higher than 10^6 Ohm

Asymmetrical 9-cell cavity with corrugated beam pipes and radius dr1 = 39 mm on one side and dr2 = 56.5 mm on another provides a good damping of HOM for all waves. The R_{sh} of 39-56.5 structure is lowest for EH_{111} (56.5-56.5 has the highest R_{sh}) and TM_{210} wave (39-39 has the highest R_{sh}).

Comparison of the results with 9-cell cavity with cylindrical beam pipes (Fig. 7), showed that Q_{ext} values for TE_{111} and TM_{110} and 2nd monopole waves are four orders higher, and 6 orders higher for quadrupole modes. R_{sh} values for 9-cell cavity with cylindrical beam pipes 100 times higher for dipole modes, 2-3 orders higher for monopole waves, 6 orders higher for first quadrupole wave.

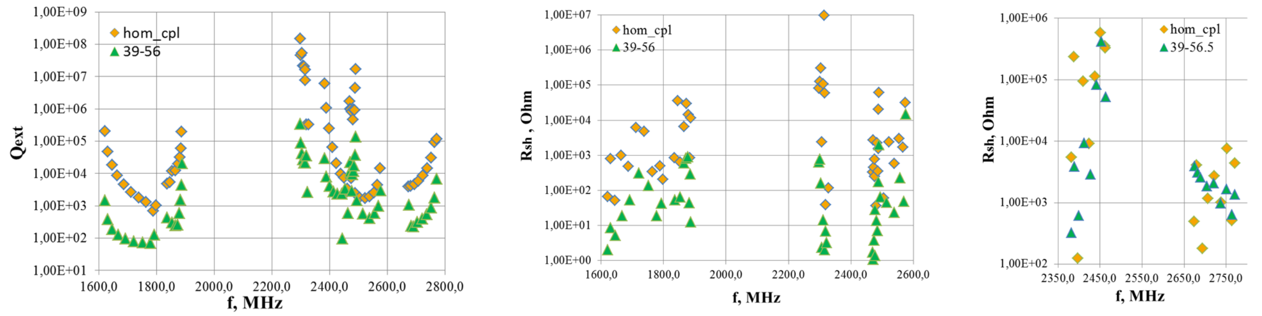
Comparison of the results with 9-cell cavity with HOM couplers (Fig. 8) showed that Q_{ext} values for waves TE_{111} and TM_{110} and 2nd monopole is two orders higher, 3 orders higher for quadrupole modes, 1 orders higher for 3rd dipole mode. R_{sh} values for 9-cell cavity with cylindrical beam pipes in 2 orders higher for dipole modes, 2-3 orders higher for monopole waves, 4 orders higher for first quadrupole wave, 1 order higher for 3rd dipole mode.



a b c

Figure 7: Q_{ext} (a), transverse shunt impedance $R_{\perp}$ (b), long shunt impedance $R_{\parallel}$ (c), for HOM’s in 9-cell cavity with cylindrical beam pipes and 9-cell cavity with corrugated beam pipe.

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB052



a b c

Figure 8: Q_{ext} (a), transverse shunt impedance $R_{\perp}$ (b), long shunt impedance $R_{\parallel}$ (c), for HOM's in 9-cell cavity with corrugated beam pipe and 9-cell cavity with cylindrical beam pipes and HOM's couplers.

CONCLUSIONS

Asymmetrical 9-cell cavity with corrugated beam pipes and radius dr1 = 39 mm on one side and dr2 = 56.5 mm on another provides a good damping of HOMs for all modes. The R_{sh} of 39-56.5 structure is lowest for EH_{111} (56.5-56.5 has the highest R_{sh}) and TM_{210} wave (39-39 has the highest R_{sh}).

REFERENCES

[1] Sergey A. Arsenyev *et al.*, Higher order mode damping in a five-cell superconducting rf cavity with a photonic band gap coupler cell, Phys. Rev. Accel. Beams 19, 081301.

[2] Z. Liu and A. Nassiri, Novel Superconducting rf Structure for Ampere-Class Beam Current for Multi-GeV Energy Recovery Linacs, Phys. Rev. ST Accel. Beams 13, 012001 (2010).

[3] Z.C. Liu, High HOM Damping Structure Study for CEPC, Proceedings of IPAC2016, Busan, Korea, pp. 2183-2185.

[4] V. Zvyagintsev, C. D. Beard, A. Grassellino, R. Bolgov, N. Sobenin, "Nine-cell elliptical cavity development at TRIUMF", Proceedings of SRF2011, Chicago, USA, July 2011, pp. 107-109.

[5] D. Kostin *et al.*, "HOM coupler design adjustment for CW operation of the 1.3 GHz 9-cell Tesla type SRF cavity", Proc. of the SRF2013, Paris, France, Sept. 2013, p. 1045.