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TRIPLE-SPOKE CAVITIES AT FZJ

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Abstract

We report the situation with superconducting triple-spoke cavity activities at the research center in Juelich (FZJ).

The Nb prototype of the 760 MHz, β=0.2 cavity is already in fabrication and should be tested this year. This work has been initiated for the European Spallation Source project.

In the frames of the new European project of High Intensity Pulsed Proton Injector (HIPPI) the 352 MHz, β=0.48 cavity is under developments. This cavity should be designed, built and tested in the Lab within next few years.

1 TRIPLE-SPOKE CAVITY PROTOTYPE

This work has been launched in the frame of the ESS project to verify feasibility of this type cavity for low-β accelerator part. The original aim was a 10-gap cavity designed for 700 MHz resonance frequency. However, it has been decided to build first less challenging triple-spoke cavity with the same cavity cross-section and spoke geometries. The only change has been made for the end gap region to equalize an electric field distribution along the cavity. This resulted in the resonance frequency increase up to around 760 MHz for the triple-spoke cavity [1]. The copper cavity model has been built using the same technology that is supposed for Nb cavity manufacture (Fig.1). The low-level power measurements of the resonance frequency and an electric field profile along the cavity axe showed an agreement with numerical calculations (Table 1, Fig.2, results of two measurements are shown).

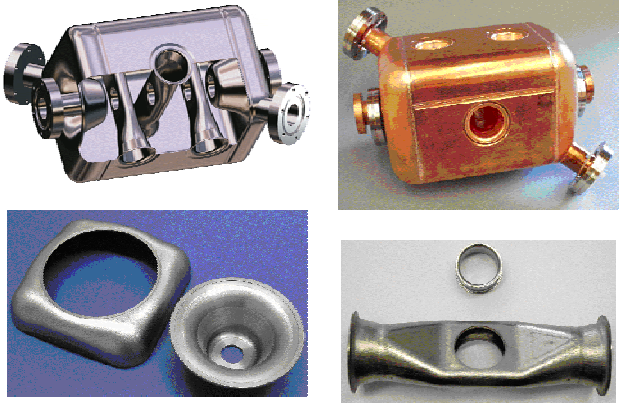

Figure 1: Triple-spoke cavity prototype – artistic view, copper model and Nb parts.

At the moment all Nb parts of the cavity are fabricated. The spokes are complete and the outer walls of the cavity are also welded. Further assembly is in progress. All welds are performed on the electron beam welding machine, which is operated by Central Department of Applied Technologies of FZJ.

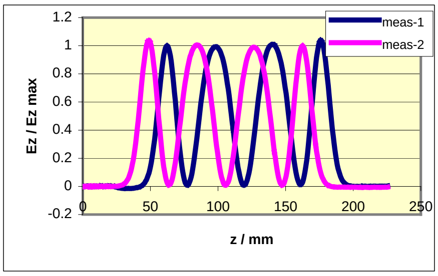

Figure 2: Field profile along cavity axis.

Table 1: Some Parameters of 4-Gap H-Cavity

Frequency	MHz	758.5
β=v/c		0.2
R aperture	cm	1.2
βλ/2	cm	4.283
R_{cav}	cm	7.15
E_{pk} / E_{acc}		4.65
B_{pk} / E_{acc}	mT/MV/m	9.19
B_{pk} / E_{pk}	mT/MV/m	1.98

2 HIPPI TRIPLE-SPOKE CAVITY DESIGN

The basics of the electrodynamics of the spoke-type cavity are well known and have been discussed many times elsewhere [2]. The electrodynamic design of any SC RF cavity aims to optimise the cavity geometry to reach the highest accelerating efficiency, in other words to minimize values of peak electrical and magnetic fields on the cavity surface relative to the accelerating electrical field on the cavity axis (B_{pk}/E_{acc} and E_{pk}/E_{acc}). The good separation of electrical and magnetic fields in the space gives a freedom to the cavity shape design. On the other hand, we limited ourselves with the case when the circumference of the spoke in any cross section is the same (except for the base cone).

The design of the end cell of multi-spoke cavity is defined by two factors – to reach the minimum of magnetic field on the spoke surface and the design of the cavity end cup. The first affects also the distribution of the electrical field along the multi-gap cavity but its profile can be corrected by the end gap length reduction.

The end cup design is mainly comes from its mechanical properties. The geometry and parameters of the cavity are shown in Fig.3 and Table 2.

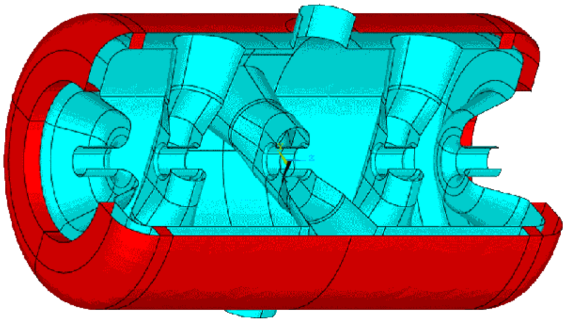

Figure 3: 4-gap H-cavity in LHe vessel.

Table 2: Some Parameters of HIPPI Triple-Spoke Cavity

Frequency	MHz	352.9
β=v/c		0.48
R aperture	cm	2.5
βλ/2	cm	20.44
R_{cav}	cm	21.1
G	Ohm	92
E_{pk} / E_{acc}		3.95
B_{pk} / E_{acc}	mT/MV/m	8.93
B_{pk} / E_{pk}	mT/MV/m	2.26

The role of the cone in the spoke base for electrodynamics is to increase the spoke diameter right in the region of the maximal B_{pk}. That moves B_{pk} from the outer spoke region closer to the middle of the spoke. It is not important for a square cavity shape as the cross section here is nearly the same but plays important role for the round cavity as it shifts B_{pk} to the region with larger distance from spoke to the outer cavity wall.

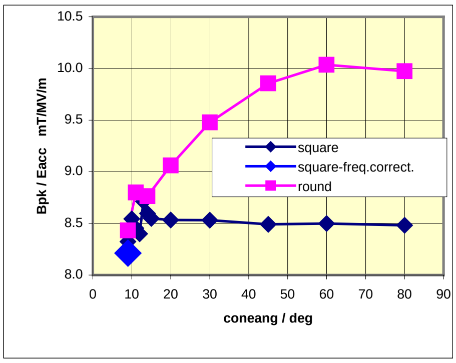

Figure 4: Peak magnetic field dependence on base spoke cone angle.

The cone geometry in the spoke base for simulations is parameterised in the way that the bigger cone diameter is always equal to the biggest spoke dimension in the mid region to let it through the hole in the outer cavity wall (the original idea of the cone use). The change of the cone angle (coneang) results in the change of cone length. By coneang=60° the whole cone geometry is outside of the round cavity, which corresponds to the straight cylindrical shape of the spoke base (Fig.4). The results mean that with the use of the spoke with the cone on its base makes the outer cavity wall shape unimportant. On the other hand, the cylindrical cavity is more attractive because of its higher rigidity.

The position of the coupler on the cavity and its type (electrical or magnetic) should be checked in terms of the Q_{ext} simulations. The position of the e-coupler opposite to the mid-spoke looks attractive because of the symmetry of its position. The magnetic field in this region equals zero. For more symmetry a vacuum port (or probe port) can be installed on the other side (Fig.5).

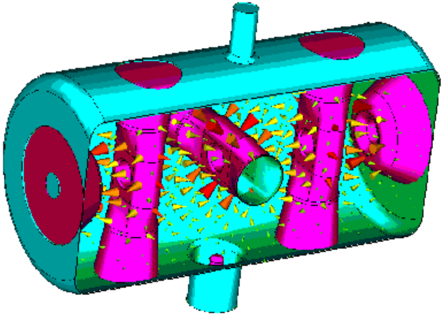

Figure 5: 4-gap H-cavity with electrical coupler and vacuum port.

Table 3: CW power requirements for the coupler for two accelerating field options and B_{pk}=80 mT.

Lcav	beam	Eacc	
m	mA	8 MV/m	10 MV/m
0.78	20	**108.10 kW**	**135.12 kW**

Bpk	**80**	mT
Epk	35.34	MV/m
E0T	8.96	MV/m
Voltage	7.28	MV
Pbeam	121.07	kW
Qext	3154770.9	

Simulations with MAFIA indicate the sufficiency of the coupling. For our beam-field parameters (Table 3) the e-coupler should be installed deep (around 40 mm) inside of the coupler port (Fig.6).

Table 4: Single-point multipacting in coaxial lines.

	CERN	HIPPI		
Z0/Ohm	75	75	75	**75**
Dout/mm	103	70	90	**100**
MP order / kW				
7	48	10.2	28.0	**42.6**
6	52	11.1	30.3	**46.2**
5	88	18.8	51.3	**78.2**
4	176	37.5	102.6	**156.4**
3	234	49.9	136.4	**207.9**
2	448	95.6	261.2	**398.0**
1	640	136.5	373.1	**568.6**

The main consideration of the coupler coaxial line size selection is multipacting. Multipacting levels can be scaled from known levels [3]. Table 4 gives the lowest seven single-point multipacting levels for the CERN LEP2 couplers and for three potential line choices. The last option (75 Ohm, 100 mm) looks fit our requirements.

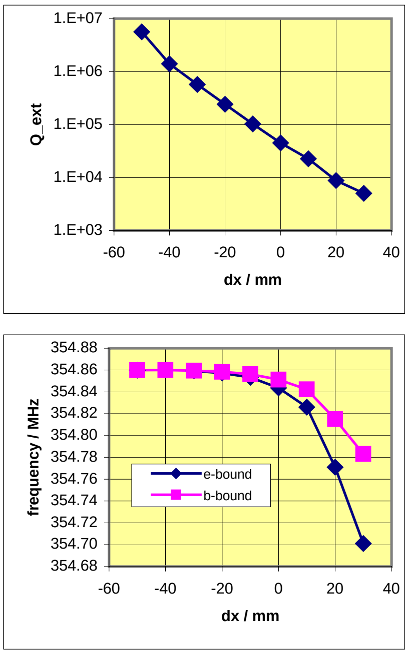

Figure 6: Q_{ext} and cavity frequency shift depending on coupler tip position relative to the cavity wall.

The most flexible element in the cavity is the end cup. This flexibility is used for reasonable deformations for cavity tuning. On the other hand, because of this flexibility it is most affected by vacuum loads cavity part. Fig. 7 shows stresses von Mises from 1 mm end cup tuning shift and 1 bar external loads. Also the cavity end cups define six first cavity mechanical eigenmodes. Provisionally, the cavity should be installed in its own He vessel. The shown tank connections with the cavity (Fig. 3) allow reducing stresses and eliminating all modes related to the end cups (now all modes are above 200 Hz).

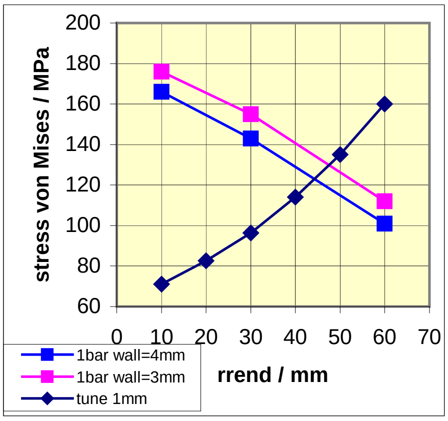

Figure 7: Stress v. Mises on cavity end cup.

The strategy of such type cavity design should include the integrated simulations of RF and mechanical properties, so called coupled analysis. The main idea and advantage of the coupled analysis (CA) with numerical codes like ANSYS is to use the same meshed model through all kind of simulations. Such CA in our case is helpful for cavity resonance frequency change calculations caused by different mechanical loads. The use of the same mesh during simulations or later the same but deformed mesh should increase an accuracy of the results (Fig. 8, Table 5).

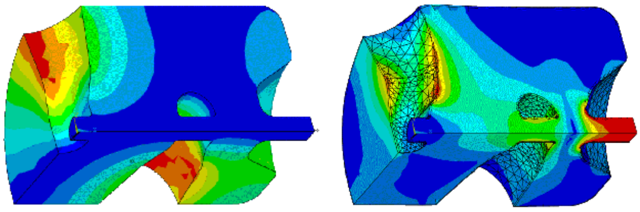

Figure 8: RF magnetic field and structure displacements caused by 1-bar loads from the cavity coupled analysis.

Table 5: Cavity mechanical properties.

tuning				
tuning sensitivity			185	kHz/mm
tuning force			10.6	kN/mm
stress v. Mises			421	MPa/mm
1 bar pressure				
fixed beam pipe				
max displacement / mm			0.123	mm
max stress v. Mises / Mpa			30-50	MPa
rf frequency shift / kHz			-27.3	kHz
free beam pipe				
max displacement / mm			0.132	mm
max stress v. Mises / Mpa			30-50	MPa
rf frequency shift / kHz			-51.0	kHz

3 ACCNOWLEDGEMENTS

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4 REFERENCES

[1] E. Zaplatin et al., "Low-beta SC H-Cavity for ESS", EPAC’2002, Paris, France, 2002.

[2] E. Zaplatin et al., "Low-β SC RF Cavity Investigations", SRF’2001, Tsukuba, Japan, 2001.

[3] J. Tuckmantel et al., “Improvements to Power couplers for the LEP2 Superconducting Cavities”, Proceedings of the PAC’95, Dallas, USA (1995).