HIPPI TRIPLE-SPOKE CAVITY DESIGN

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Abstract

In the frames of the European project of High Intensity Pulsed Proton Injector (HIPPI) the 352 MHz, beta=0.48 triple-spoke cavity is under development and will be built at the Research Centre in Juelich (FZJ). The criteria and results of the cavity RF and structural analyses are presented. The fabrication of cavity parts and support structures has been started. All parts will be manufactured first in copper in order to check the supports and the welding conditions of the ensuing niobium parts.

CAVITY RF PARAMETERS

The cavity electrodynamics design aimed 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 geometry and parameters of the cavity are shown in Fig.1 and Table 1. The detailed cavity RF analyses have been published elsewhere [1].

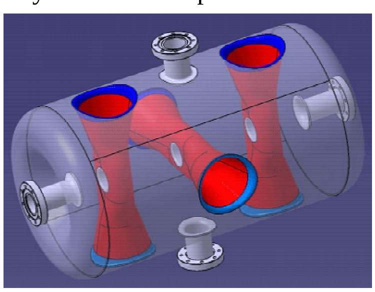


Figure 1: 3D view of the HIPPI triple-spoke cavity.

STRUCTURAL DESIGN

Modal analysis

The very first cavity investigation in terms of the mechanical properties is its mechanical eigen modes. We use the criterion of 200 Hz for the first mode that would be sufficient for the cavity rigidity. To improve the cavity rigidity the stiffening rings on both cavity ends are used (Figure 2). The stiffening rings are 4 cm high and 2.5 cm wide. The cavity fixation in four points by every ring is arbitrary and not practical but it allows investigating the modes that related only to the cavity (Table 2).

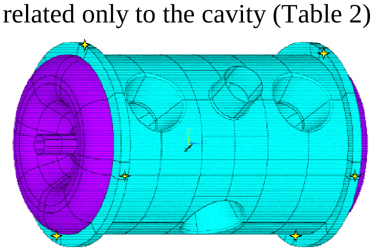


Figure 2: Cavity simulation model for modal analyses.

Table 1: Some parameters of HIPPI triple-spoke cavity

Frequency	MHz	352
β=v/c		0.48
R_aperture	cm	2.5
$\beta\lambda/2$	cm	20.44
Cavity radius	cm	21.7
Cavity length	cm	78
QR_s	Ohm	93
E_{pk} / E_{acc} *)		465
B_{pk} / E_{acc} *)	mT/MV/m	10.97
*) $L_{cav} = N_{gaps} * \beta\lambda/2$, where N_{gaps}=4 - number of gaps		

Table 2: Cavity eigen modes with non-stiffened end cups

	with ring	no ring
Mode	**Frequency / Hz**	**Frequency / Hz**
1	261	155.1
2	294.5	251.2
3	298.6	253
4	298.7	274.8
5	418.2	353.7

Pressure Response

The further strategy of cavity design should include the integrated simulations of RF and mechanical properties, called coupled analyses (CA). 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.

The possible way of the cavity tune is to apply the tuning pressure to the cavity walls close to the central spoke in the region of the maximum of magnetic field (Figure 3). The simulations result in 75 kHz/mm tuning sensitivity for the relatively local pressure application. There are advantages to install the tuner in this place rather as usual at the cavity ends – first, one saves space between the cavities that reduces accelerator length, and second, the required tuning force is much lower as it should not deform the stiffened end cup but only the 3-4 mm thick niobium wall. Disadvantage is that the tuning sensitivity is lower.

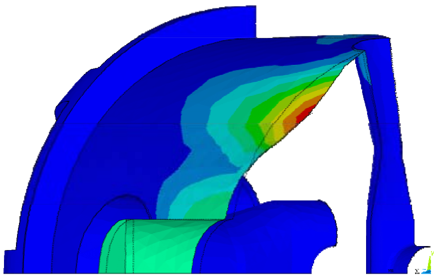


Figure 3: Cavity deformations by tuning close to middle spoke.

For the structural design, cavity end cups are the most flexible elements of the structure. Let's consider the option with additional end cup stiffening ribs (Figure 4). The ribs are 10 deg. wide, which should automatically follow the end cup surface increase with radius. It makes end cup rigidity increase with radius. Assuming that the end cups do not move at all, the frequency shift from 1 bar pressure would be defined mainly by the magnetic field volume change (cavity inductance reduction). The end cup displacement caused by 1-bar pressure results in the last gap length reduction (cavity capacitance increase). It means both effects work in the different direction of the cavity frequency change. Hence, one can find the end cup stiffening that would result in end cup deformation, which would compensate the frequency change because of magnetic field volume change (Figure 4). An uncertain factor here is the end cup wall thickness. We investigated two different cases for end cup wall thickness (3 and 4 mm for end cups, the rest cavity including spokes is 4 mm). One can see on pictures that the maximum deformation moves from end cup to the cavity wall. It is impossible a priori to predict the final wall thickness. That's why one should foresee the possibility to adjust the structure to the final conditions. One-way is to build the ribs as high as possible and after initial measurements to cut them in the region of the main deformations making them less rigid. This method is rather close to the conducted simulation of the rib height variation. The other way is to make the deep and short cut in the same region. The uncertainty with the cavity wall thickness changes the results of the structure optimisations. This makes the possibility of the final structure adjustment highly necessary. The use of the tuner in the place of the maximum magnetic field means the ideally complete fixation of the wall in this place. This results in a lower frequency shift caused by magnetic field change and as a result „overcompensation“ by the end cup displacement. In this case to reach the complete compensation one should either provide bigger end cup stiffening or one could use the tuner as an additional tool for cavity frequency shift adjustment.

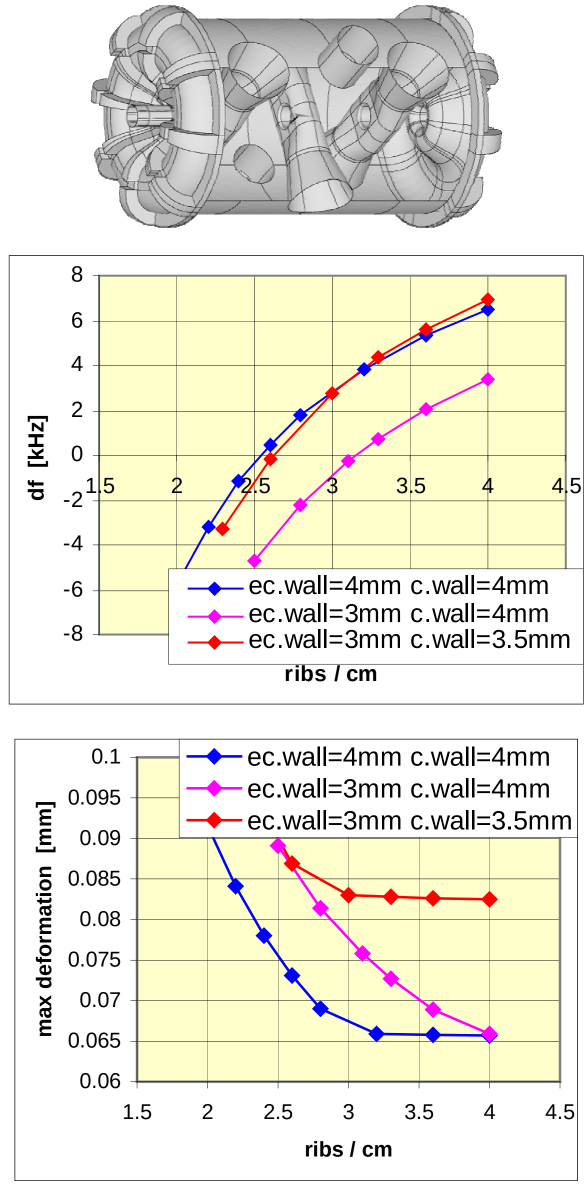
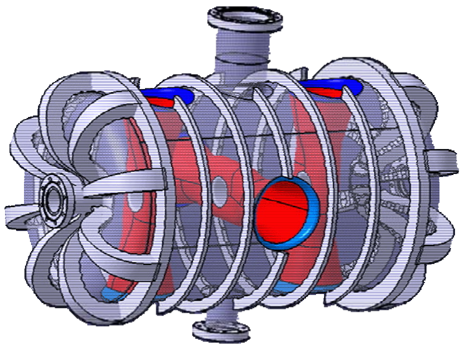


Figure 4: Cavity with stiffening end cup ribs and cavity reaction on 1 bar external loads vs. rib heights.

Lorentz force detuning.

The action of the Lorentz forces in the region of the magnetic field is directed outside, which is opposite to the action of the 1 bar pressure. It means that the effects of cavity wall and end cup deformations have to be added. In this case the use of the tuners (say, cavity wall fixation in these places) reduces Lorentz force cavity detuning.

For further LFD reduction one could use small rings (1 cm x 2.5 cm) on the cavity walls in the regions of maximal deformations (Fig.10). LFD ring installations will also affect the cavity frequency shift caused by 1 bar pressure. LFD rings should be installed as the tuner will compensate the bigger LHe pressure detuning and LFD will be lower. Let's finally note, that investigations and optimisations of all effects are within 0.1 mm, which mean strong uncertainties between simulations and the final cavity geometry as the tolerances on cavity manufacturing are within 0.5 mm. Nevertheless, the final practical cavity adjustment is possible if the methods of fine-tuning are included in the mechanical cavity design beforehand.With a use of LFD rings the dependence on the cavity wall thickness for the frequency shift is negligible.



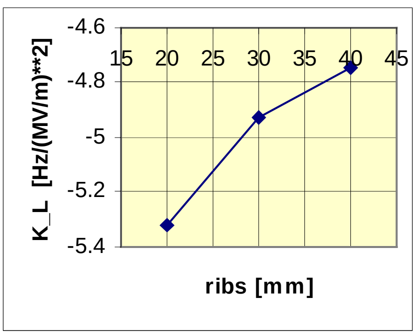


Figure 5: Cavity with stiffening end cups and Lorentz force rings and cavity reaction on Lorentz forces vs. end cup rib heights.

CAVITY FABRICATION PROGRESS

The cavity body will be made of two half shells, both fabricated by rolling. Both longitudinal seams will be welded in the new electron beam-welding machine (Figure 6), providing the required chamber size of 4 m³.

The plant has a 15 kW beam gun with a maximum accelerating voltage of 170 kV. The freely programmable beam deflection and various CNC components permit a welding of complex construction units and multidimensional structures. The chamber size of 4m³ with maximum weld dimensions of 960 x 590 mm and oil-free vacuum pumps guarantee a high availability for the various welding tasks of this large cavity unit. A universal turning device and the option to operate the beam gun horizontally supply the handling requirements of this complex cavity design.

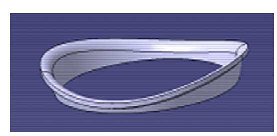
The end cups have a rotational-symmetric design and will be formed completely by a spinning process. The first prototypes of copper caps could be considered satisfactory concerning the rather homogeneous distribution of the wall thickness, even in the middle area with a high deformation degree.

Figure 6: New electron beam welding machine.

The spokes consist of two half shells, each formed by deep drawing (Figure 6). The finish machined half shells are then electron beam welded, followed by EB welding the adapter rings onto both ends of each spoke.

Spoke half after deep drawing

Welded spoke



Adapter ring

Copper end cup prototype after spinning

Figure 7: Different parts of the cavity.

ACKNOWLEDGEMENT

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE, contract number RII3-CT-2003-506395)

REFERENCES

[1] E. Zaplatin et al., “Triple-Spoke Cavities at FZJ”, EPAC’04, Lucerne, July 2004, http://www.jacow.org.