FZJ SRF TSR WITH INTEGRATED LHE VESSEL

E. Zaplatin, Forschungszentrum Juelich, Germany

Abstract

Single- or Multi-Spoke SRF cavities are one of the basic accelerating structures for the low and intermediate energy part of many accelerators. Different types of external loads on the resonator walls predetermine the main working conditions of the SC cavities. The most important of them are very high electromagnetic fields that result in strong Lorentz forces acting on cavity walls and the pressure on cavity walls from the helium tank that also deforms the cavity shape. For the accelerators operating in pulsed regime the Lorentz forces are the dominant factor. The liquid helium vessel pressure instability even for 2K operations is the source of large microphonics and dominates for cw operation. Here we propose an innovative integrated helium vessel-cavity and stiffener design that will provide an effective passive damping minimizing df/dp ratio. Minimizing df/dp may be accomplished without an enhancement of the structure rigidity, which in turn minimizes the load on the cavity tuner. A separate stiffening scheme reducing Lorentz force cavity detuning to be added without violation of df/dp optimization.

The developed at the Research Center in Juelich, Germany (FZJ) the 352 MHz, $\beta=v/c=0.48$ Triple-Spoke Resonator (Fig. 1) was used as an example to demonstrate the proposed conceptual integrated helium vessel-cavity design.

NAKED CAVITY DESIGN

During SC cavity RF design fabrication technology and structural parameters have to be taken into account. The whole RF design has to be greatly adapted to two main goals - the simplest technology of cavity manufacture and to achieve the best possible mechanical parameters (Lorenz force frequency shift, frequency pressure dependence, resonator tuning scheme and microphonics mitigation).

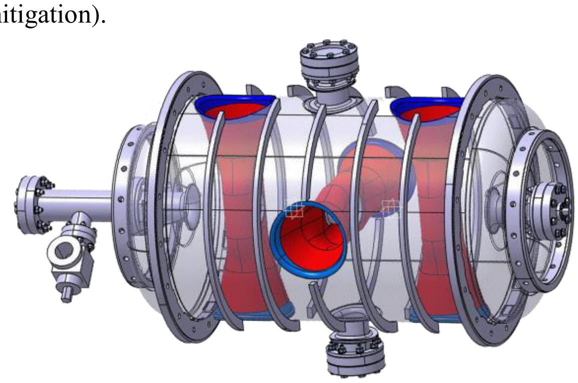

Figure 1: 3D view of FZJ triple-spoke cavity.

The most effective way for the frequency pressure dependence (df/dp) minimization is to find the resonator stiffening scheme that would balance frequency shifts from magnetic and electric stored energy changes caused by the cavity shape deformations. Such self-compensation frequency shift design for multiple-cell resonators was first investigated for the low-beta triple-spoke cavities (see for instance [1-3]). The summary of FZJ TSR structural behaviour can be accurately generalized to the case of arbitrary boundary conditions, characterized by its longitudinal stiffness K_{ext}, (Fig.2).

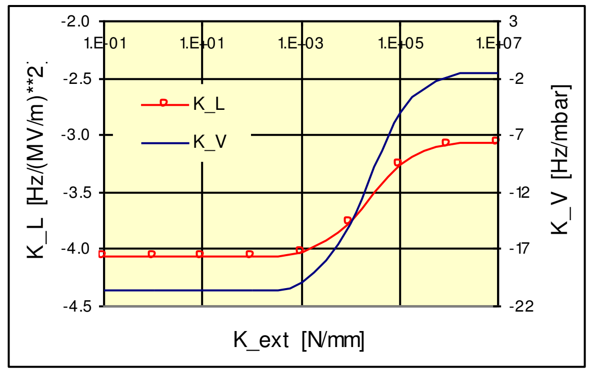

Figure 2: TSR structural analyses results.

MULTI-CELL CAVITY STIFFENING

Based on investigations within HIPPI [3] the new detailed developments of the integrated cavity-helium vessel design to fulfil the main requirements on resonator mechanical parameters were provided. The simulation model (Fig. 3) consists of the resonator surrounded by the cylindrical helium vessel (HV) with rounded end cups. HV connected to the cavity via four rings with two direct joints with beam pipes. The model of both HV end cup rings has possibility of disconnecting HV with the cavity (left/right end cup ring joints). There are possibilities simulating of the slots (left/right end cup slots) in the model of the both HV end cups. The radius of slots R_{slot} can be varied during calculations.

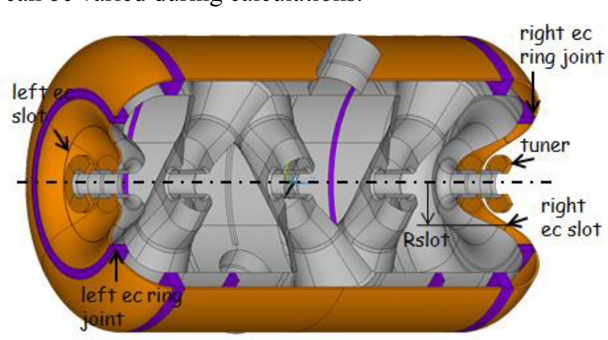

Figure 3: TSR simulation model with helium vessel.

HV constraints consist of the fully fixed right ring connecting cavity with HV. A left beam pipe is supposed to be completely free for all simulations. The structure mechanical tuner is supposed to be installed at the right beam pipe end flange and during calculations can be simulated as fully fixed or unconstrained. The response of the cavity to a pressure differential was calculated with vacuum inside the resonator and ambient pressure is inside spokes and between the cavity and helium vessel walls.

The main idea of HV/cavity structural design is to find the set of constraints that will secure the conditions of the minimization of microphonics, Lorentz force cavity detuning and tuning pressure. Since the cavity has been already built (as a naked option) [2] no any modifications or adjustments in RF design were foreseen. Asymmetrical resonator constraints do not cause any substantial accelerating field profile change because of the high gap-to-gap coupling secured by unified magnetic field distribution in the cavity.

Several options of different combinations of the structure design and constraints were investigated. Here we present two most interesting schemes of TSR helium vessel structure. The first one is the structure with right end cup slot and left end cup ring connected to the HV end cup.

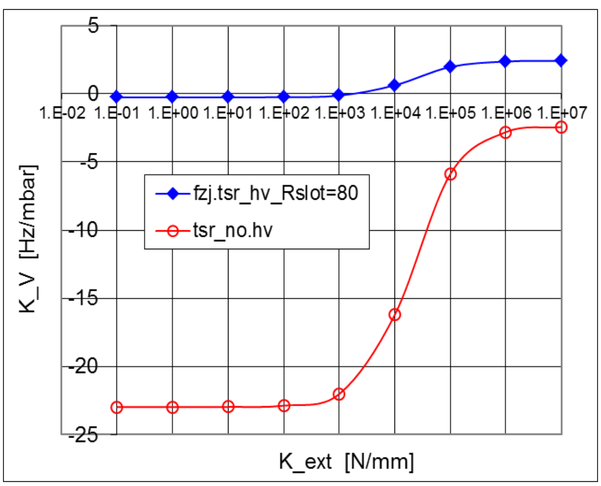

Figure 4: TSR simulation df/dp vs tuner stiffness (HV constraints option 1).

The right end cup slot is used eliminating HV end cup deformation to reduce the tuning pressure. The simulations were done for both fixed/free tuner flanges constraints. With a fixed tuner df/dp doesn't depend on R_{slot} since the cavity constrain conditions are the same for any R_{slot} value. With a free tuner df/dp results detect that the cavity deformations cause the reduction of the stored electrical energy (a resonator frequency shift is positive) by a large slot radius R_{slot} (deformation of the cavity right end cup mainly outwards) and its enhancement by small R_{slot} (cavity right end cup is deformed mainly inwards the resonator). This effect results in df/dp dependence crossing a zero value with R_{slot} variation. As a result the df/dp detect rather small dependence on tuner stiffness (Fig. 4) for a certain R_{slot} value.

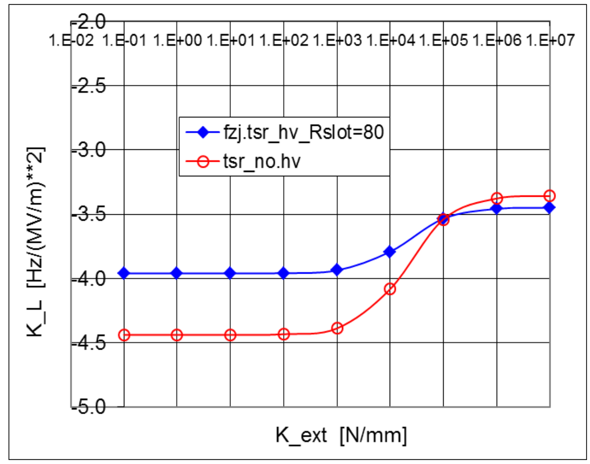

Figure 5: TSR simulation model with right end cup slot and left end cup ring is connected to the HV end cup (option 1).

Lorentz force detuning is defined mainly by the resonator end cup deformations (Fig. 5). HV end cup ring joints reduce the deformations.

To have more flexibility for electrical field distortion compensation the simulations were made for the structure with both end cup slots, right end cup ring connected to the resonator end cup. In this case df/dp is defined mainly by the both cavity end cup deformations. R_{slot} variation should be used to optimize df/dp. A right side of the cavity is more rigid and only slightly affects the results. A small R_{slot} variation can be used to adjust df/dp value to the corresponding value of the tuner stiffness (Fig. 6).

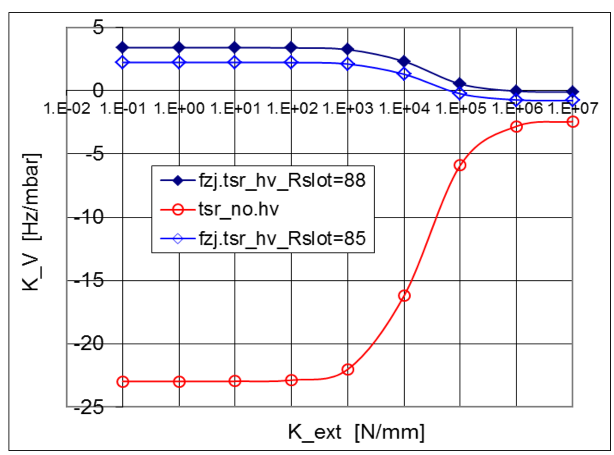

Figure 6: TSR simulation df/dp vs tuner stiffness (HV constraints option 2).

The Lorentz force detuning is defined again mainly by the resonator end cup deformations and do not differ much from the option 1.

For these model constraints (both end cup slots, right end cup ring is connected to the resonator end cup, end cup slots are used eliminating HV end cup deformation to reduce the tuning pressure) the structure tuning sensitivity is -82 kHz/mm with the required tuning force is around 22 kN/mm. This could force to adjust the resonator RF design to reduce the required tuning pressure. No

ISBN 978-3-95450-169-4

electrical field profile change along the beam path is detected.

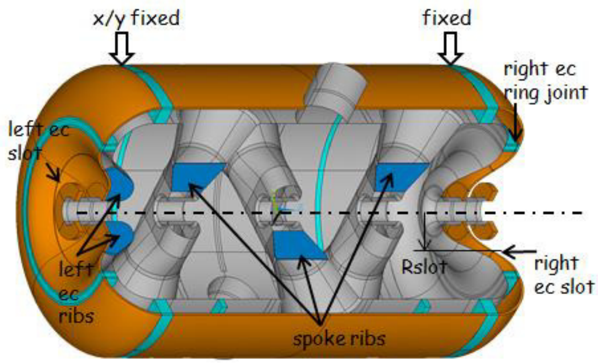

Figure 7: 5-cell cavity with helium vessel model for two-side tuning simulations.

Some possible cavity stiffening scheme modifications to improve the structure mechanical properties were investigated. These modifications should result in the better Lorentz force detuning parameters. The cavity Lorentz force detuning is defined also by the spoke deformations. The inward deformations of the spoke low parts in electrical field region are caused by the outward deformations of the less rigid spoke upper parts at the strong magnetic field regions. To reduce spoke deformations additional ribs installed inside spokes were modelled. There are also four additional radial ribs at the iris region of the resonator left end cup to improve its rigidity. Using radial ribs also at the tuner (right) side would strongly increase the tuning force (see Fig. 7).

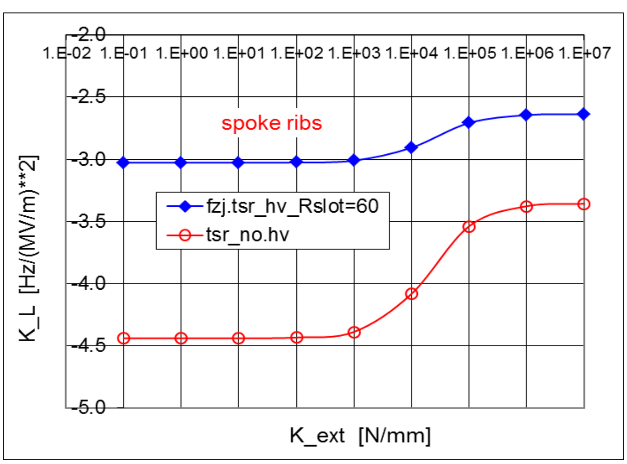

Figure 8: 5-cell cavity with helium vessel results of eigen mechanical modes.

There is a substantial reduction of LFD since spoke deformations at the lower electrical spoke parts were nearly eliminated (Fig. 8). Simulations of df/dp detect that there is nearly no dependence of df/dp on the tuner stiffness (Fig. 9).

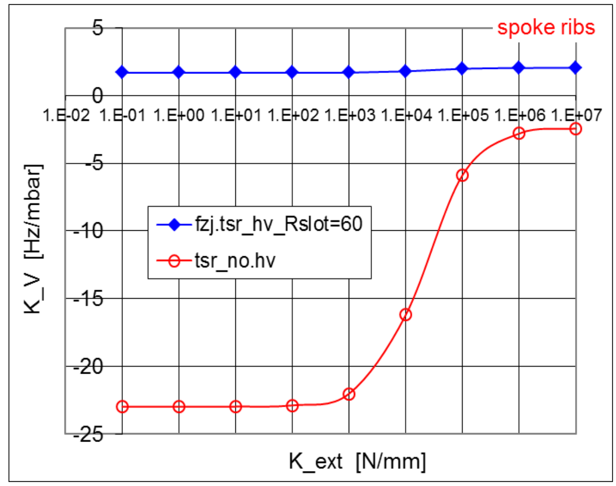

Figure 9: 5-cell cavity with helium vessel results of eigen mechanical modes.

CONCLUSIONS

1. An integrated with triple-spoke resonator liquid helium vessel design can be effectively used to minimize the level of microphonics caused by external pressure on cavity walls.
2. The resonance frequency shift resulted from Lorentz forces cannot be eliminated completely because of their inherent properties but can be minimized adjusting a resonator stiffening scheme for df/dp optimization.
3. The tuning procedure with an application of the tuning force at one cavity side doesn't affect nearly at all an accelerating electrical field profile along the resonator axes.
4. The wall thickness may be significantly different from the initial thickness of the sheet niobium after the cavity is formed and etched. This requires additional developments of tools that would allow fine df/dp adjustments after complete of the cavity-helium vessel structure manufacturing.
5. An accuracy of the numerical simulations can be the source of the difference between theoretical model and the realized structure parameters.

REFERENCES

[1] E. Zaplatin et al., "HIPPI Triple-Spoke Cavity Design", EPAC'06, Edinburgh, UK, 2006.
[2] E. Zaplatin, et all, "FZJ HIPPI SC Triple-Spoke Cavity", PAC2009, Vancouver, Canada, 2009.
[3] E. Zaplatin, "FZJ HIPPI TSR", HIPPI Final General Meeting, Geneva, Switzerland, 2008.