COSY SC HWR INVESTIGATIONS

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Abstract

This paper contents the results of COSY SC Linac cavity prototype (160 MHz, ß=0.11) simulations. The main purpose of the work was to get as much as possible information about this particular cavity and in some extend to investigate this type cavity general parameters for broader application.

The main effort of investigations has been devoted to provide structure coupled analysis with ANSYS. This allows using the same cavity numerical model with the same mesh for electrodynamics and structural analysis. The cavity frequency shift caused by structure cool-down, LHe pressure and tuning deformations using this method are evaluated.

The specific questions of cavity manufacturing are discussed.

INTRODUCTION

The requirements for thermo-mechanical properties of RF cavities are especially stringent for superconducting (SC) structures. The main task of SC cavity designer is to predict the interactions between electromagnetic fields and mechanical structure to foresee the tuning strategy and to evaluate the stability of the system for further its mechanical layout. Computer aided design tools should be extensively used throughout the design of the structure to determine the optimum mechanical environment.

For these multi-physics purposes the most powerful tool are ANSYS [1] codes which include the possibility to perform the coupled analysis between electro-magnetic and thermo-mechanics using the same model. The data exchange between different tasks is a built-in feature of the package, which simplifies the simulation procedure and should reduce the calculation error.

SIMULATIONS

The cavity of investigation is a well-know half-wavelength resonator, which is supposed to operate as one of the accelerating cavities for COSY Injector linac [2]. Its working RF frequency is 160 MHz for proton velocity v/c=0.11 (Fig. 1).

The analysis of HWR has been made to find the resonant frequency shift caused by structure cool-down, LHe pressure and tuning deformations, the model predictions for peak stresses, deflections and flange reaction forces under vacuum loads and room temperature, and also for forces required to produce a specified tuning deflection. An important part of simulations is devoted to the determination of resonant structural frequencies. The simulation results should help to evaluate the required cavity layout in the cryostat environments [3].

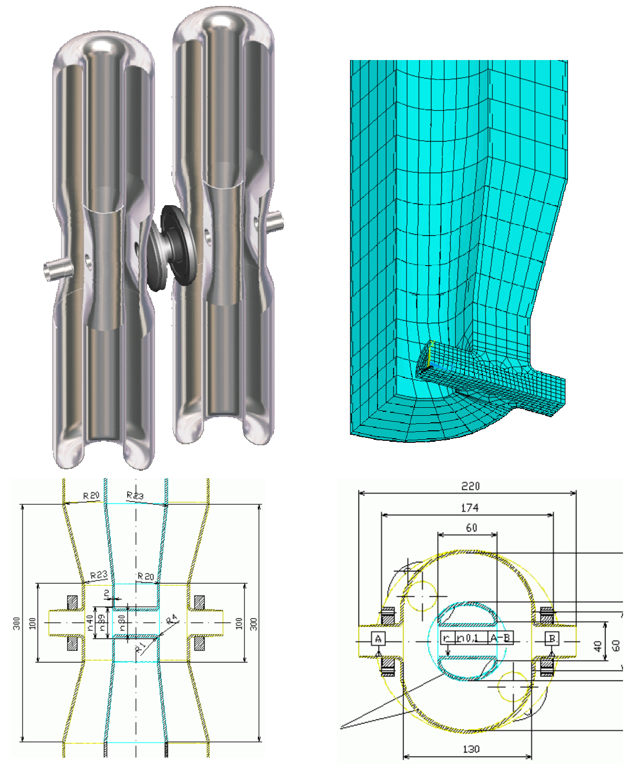


Figure 1: Two COSY Injector Half-Wave Resonators, their geometry and simulation model.

The whole HWR is supposed to be produced out of 3 mm thick niobium sheets. The following parameters of niobium are used:

Young's modulus E=105000 N/mm^2,

Density ρ=8.57 g/cm^3,

Poisson number ν=0.38.

The Young's modulus of niobium is in the wide temperature range invariable, also in the range of the cryo-temperatures. We use yield strength 500 MPa as a reference measure [4] in our calculations.

The simulations have been made with ANSYS codes.

An analysis started with the inner cavity volume model and computation of the steady state frequency by using ANSYS RF domain. To check the correspondence of simulations we compared results with MAFIA and MWS codes (Table 1). By these calculations we didn't try to reach the ultimate accuracy and in every program used different meshed model. After that around the inner volume model the cavity walls have been built using so-called shell elements for further structural simulations (Fig.1).

Table 1: HWR RF Simulations

	MAFIA	MWS	ANSYS
Freq / MHz	159.78	161.08168	160.606974

LHe Pressure

By the analysis of the cavities under LHe loading conditions all structure surfaces are under 1 atm extra pressure including the surfaces of inner electrodes as they are supposed to be filled with a liquid helium (Table 2). We added the data for two extreme cases by 1.8 and 2.5 Bars.

Table 2: HWR under LHe Pressure.

	1.0 bar	1.8 bar	2.5 bar
Max displacement	0.171 mm	0.308 mm	0.428 mm
Freq. shift	-32258 Hz	-58262 Hz	-81160 Hz
Max Stress	81 MPa	146 MPa	203 MPa
Freq. / MHz	160.574715	160.548711	160.525813

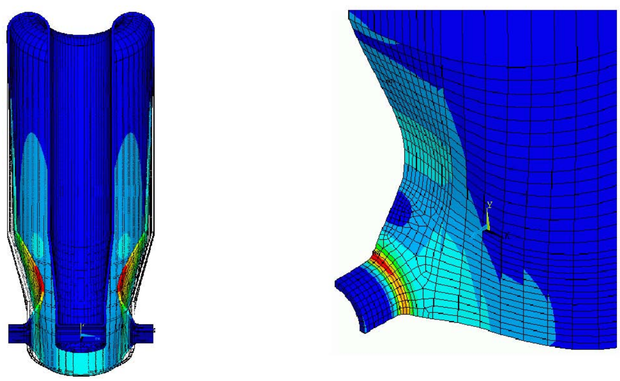


Figure 2: HWR under LHe pressure (displacements and stress von Mises)

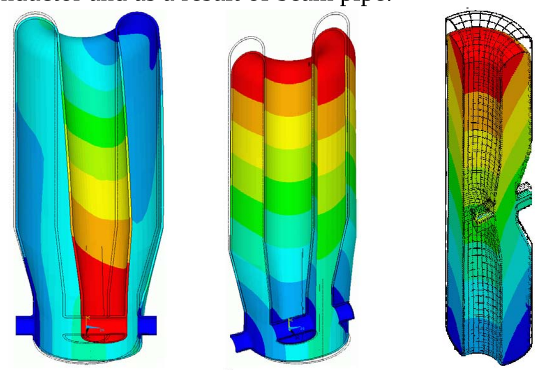
The main deformations occur in the electric field region (Fig.2). The beam pipes have been fixed in these simulations. The results mean that by vacuum test at the room temperature the beam pipes should be free.

Cool-Down

The cavity is supposed to be assembled at room temperature and then cooled down to 4.2 K. The cavity cool-down results in the biggest frequency shift and structure deformations. Most accurate and full calculations have to be made during cavity-helium vessel assembly design. Fig. 3 shows the cavity behaviour by cool-down under different support conditions. Any addition suspensions like vacuum and coupling ports could bring additional deformations and should be investigated separately.

For the case shown on Fig. 3,c that is most close to the cavity position in the test cryostat the max displacement is about 2 mm, which will result in 370 kHz frequency shift. At the same time the beam pipe vertical displacement of the inner conductor is 1.1 mm.

Here we limit ourselves by the case of cavity degree of freedom with cavity bottom fixed. In the real design some addition suspensions like vacuum and coupling ports will make the structure even more rigid, on the other hand it could produce asymmetric displacements of inner conductor and as a result of beam pipe.



a Max displ. 3.55 mm
b Max displ. 0.96 mm
c Max displ. 2.0 mm

Figure 3: HWR under Cool-Down.

Modal Analysis

The main purpose of these simulations is to find the best way to fix the cavity in the cryostat that should eliminate the lowest mechanical modes. The boundary conditions (constrains) for our model are the both beam pipe ends completely fixed against displacements in any direction (by tuner or continuous beam pipe), which correspond to the degree of freedoms in the test cryostat. The following simulations show the first results, which give a representation about mechanical stability of such cavities (Fig. 5). The final simulations with real cavity degrees of freedom should be provided afterwards.

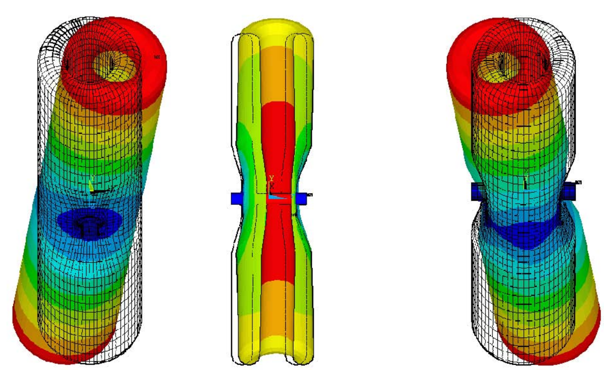


Figure 5: Modal Analysis Results.

Tuning

The mechanical tuner of HWRs consists of two parts: a stepper motor driving the coarse tuner and a piezo fine tuner mounted outside of the cryostat. For both tuners the tuning forces applied to the cavity around the iris joint of beam pipe and cavity wall. Several simulation models have been built to investigate cavity behaviour under tuning pressure. The coupled analysis models give the tuning sensitivity from 250 to 350 kH/mm. The calculations of tuning with MWS when tuning deformations simulated with ball surface (Fig. 7) resulted in 120-200 kHz/mm dependent on tuning depth.

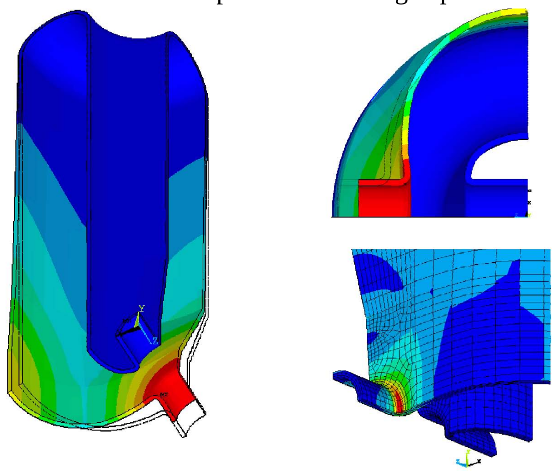


Figure 6: HWR under tuning pressure in ANSYS model (displacements and stress von Mises)

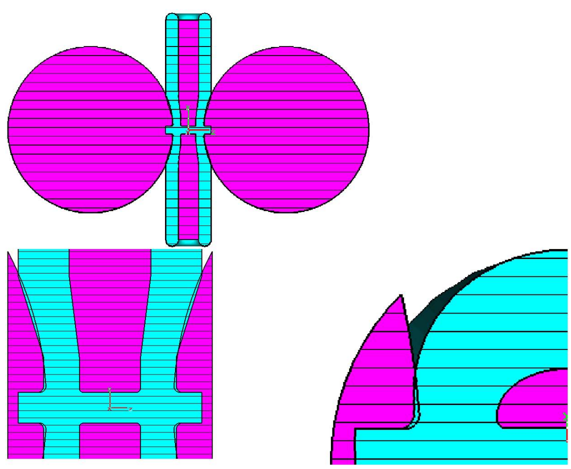
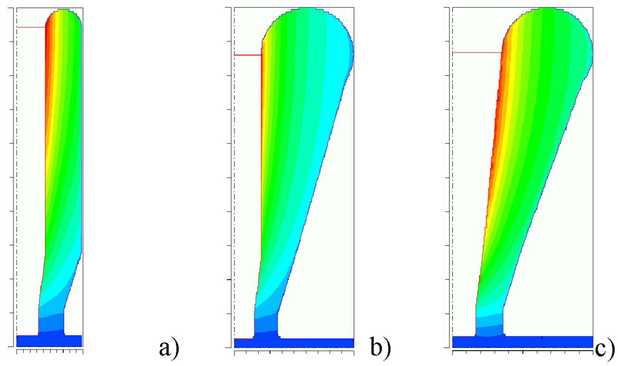


Figure 7: HWR under tuning pressure in MWS model

Two additional ANSYS models simulating only cavity walls have been built to check coupled analysis calculations. All of them showed very close results of around 2.2 kN/mm tuning force. The biggest stress von Mises is around cavity iris (250 MPa/mm at R_{iris}=6 mm) that favours the bigger radius of beam pipe and cavity wall joint.

Easy Cavity Upgrade

It is well known that in this type of cavity the limitation on accelerating efficiency first comes from the magnetic field region. To minimize the B_{pk}/E_{acc} the easiest way is to increase the volume in top/bottom cavity regions (Fig. 8b). The further improvements related to the current density minimization that results in the inner conductor diameter increase (Fig. 8c).



B_{pk}/E_{acc}=9.79 mT/MV/m | B_{pk}/E_{acc}=8.16 mT/MV/m | B_{pk}/E_{acc}=5.6 mT/MV/m

Figure 8: HWR magnetic field region improvements

To keep the same longitudinal cavity length of installation we proposed the cross-cavity layout (Fig. 9) [5].

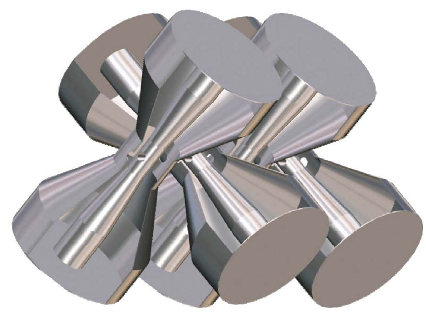


Figure 9: Four conical HWR cross-cavity installation

HWR-PROTOTYPE: MANUFACTURING

In order to compare different manufacturing techniques two prototypes are ordered at two different companies. The manufacturing process of the inner and outer conductor will be different especially concerning the welding sequence.

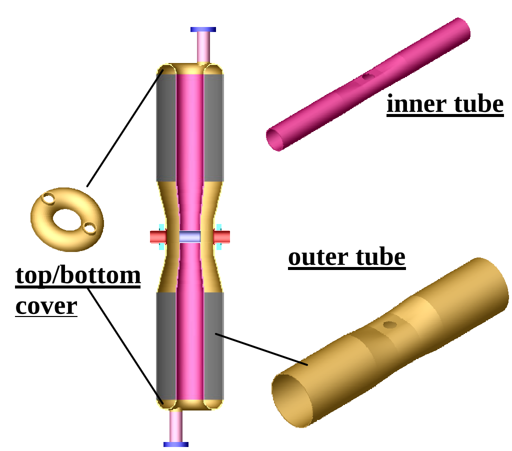


Figure 10: HWR main components

The design of the top and bottom cover has been split into one deep drawing type out of a 3mm sheet and one turned workpiece out of a 20mm plate (see fig. 11).

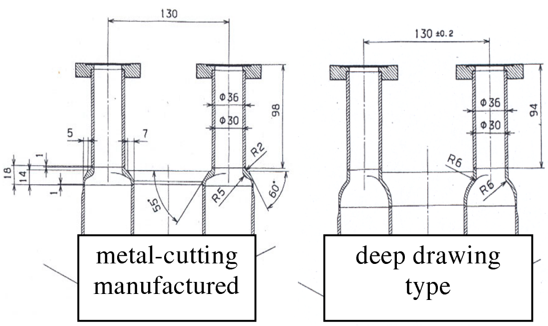


Figure 11: Different designs of the top/bottom cover.

Different forming techniques were compared and different designs of inner and outer tube resp. top/bottom cover were analyzed.

The following different aims can be specified:

- compare different manufacturing techniques and different technical designs.
- optimize the technical design according to manufacturing (time, costs, quantity of welding seams, …)
- optimize the design according to physical function (round shape, welding seam out of critical areas (E-, B-Field), …).

Outer conductor tube:

In general the outer conductor can be manufactured out of tubes (seamless or welded) or out of sheets. That will result in three main types of manufacturing.

In the first case the tube can either be splitted up in three pieces, which have to be welded circumferential (two welding seams). The middle part will be formed by deep drawing out of two sheets and the two end pieces can be manufactured out of seamless tubes or out of sheets containing one welding lengthwise.

The second case is to manufacture the whole tube out of two sheets by deep drawing including two weldings lengthwise.

The third possibility is to manufacture the outer conductor tube out of a (seamless or welded) tube by high-pressure hydroforming.

The first and second possibilities will be realized during fabrication of the first two prototype cavities. For the third one there were made further theoretical investigations before the forming tests them will follow. In addition to the feasibility some calculations have been made concerning stress and strain during the forming process and the reduction resp. increasing of material thickness. Several calculations with different tube diameters were compared regarded to the equivalent stress and strain resp. the true logarithmic deformation. Fig. 12 gives an example for a tube diameter 150mm as the initial shape of the tube. That value is about 17mm lower than the elliptical periphery of the middle part of the outer conductor tube so that the material thickness decreases. The material thickness in the middle part results in 2.63mm while the outer parts or the outer tube decrease to 2.4mm. The plastic deformation reaches a critical value near to the equivalent stress and strain value of Niobium. The optimum result will be reached with a tube diameter of about 167mm as initial shape so that the periphery of the tube has the same value than the periphery of the middle part of the outer conductor tube.

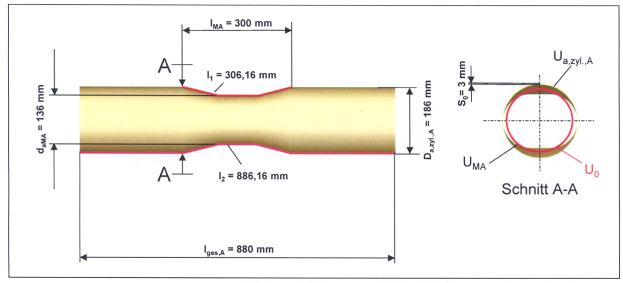


Figure 12: Analyzing of wall thickness reduction for high-pressure hydroforming of the outer conductor

Inner conductor tube:

According to the outer conductor tube the inner conductor tube can be manufactured in different ways.

The prototype cavities both will be manufactured out of sheets by deep drawing.

Nevertheless the possibility of using a tube (in favor seamless) is very interesting. The calculation shows very good results by using a tube diameter of 78mm. The material thickness varies from 2.9mm to 3.1mm and the grade of deformation is nearly negligible.

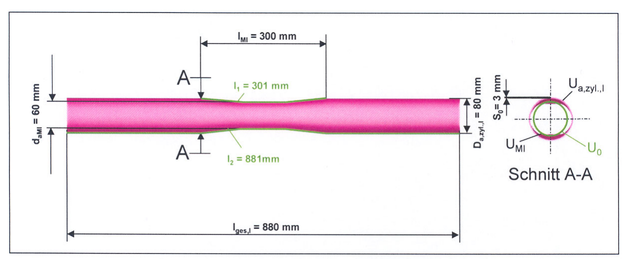


Figure 13: Analyzing for high-pressure hydroforming of inner conductor

Top/bottom cover:

The top and bottom covers of the prototype cavities were manufactured out of sheets by deep drawing and out of a thick plate by metal-cutting manufacturing (Fig. 11). Another possibility is to manufacture the top and bottom cover by spinning. The change of the material thickness is negligible.

The calculated sheet dimension for this process is shown on Fig. 14. In a second step the connection for the two tubes can be fabricated by collar forming.

Another interesting manufacturing technique for this workpiece will be again the high-pressure hydroforming. In contrast to the spinning technique the manufacturing could be realized in one step. First forming test will start soon.

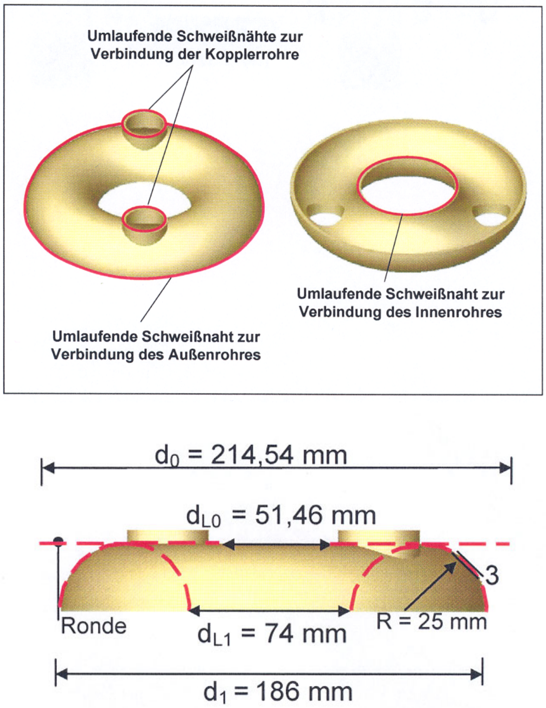


Figure 14: Calculated sheet dimensions for the spinning process.

REFERENCES

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