STATUS OF THE TUNER FOR THE 19-CELL SUPERCONDUCTING CH-PROTOTYPE CAVITY

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Abstract

The radio frequency tuning of the multi-cell superconducting CH structure for low and medium beta values is investigated for a 19-cell niobium prototype cavity with $\beta = 0.1$. By applying external mechanical forces the deformation of the structure is studied and the resulting change in frequency is analysed. The ruling equations of elasticity and the electromagnetic eigenvalue problem are solved by using commercial finite element tools. The quantitative results form the basis of an optimized tuning device. In order to guarantee a long lifetime of the cavity, fracture criteria are defined to avoid mechanical damage. Wherever possible the results are compared with experimental data obtained from measurements performed on the first CH prototype developed at the Institute of Applied Physics (IAP) at Frankfurt. In addition a fast piezo device will be integrated into the slowly acting mechanical tuner. The whole system will be integrated into an existing horizontal cryostat for testing purposes.

INTRODUCTION

The superconducting **C**rossbar-**H**-type **CH**-structure is a multicell drift tube cavity operated at the $H_{21(0)}$-mode. It is designed for protons and ions in the low and medium energy range [1]. A 19-cell, $\beta = 0.1$ prototype cavity with a length of 105 cm and a diameter of 28 cm has been developed at the IAP in Frankfurt. The corpus of the cavity is made of niobium sheets with a thickness of 2 mm and a RRR-value of 250. Figure 1 shows a schematic picture of the structure.

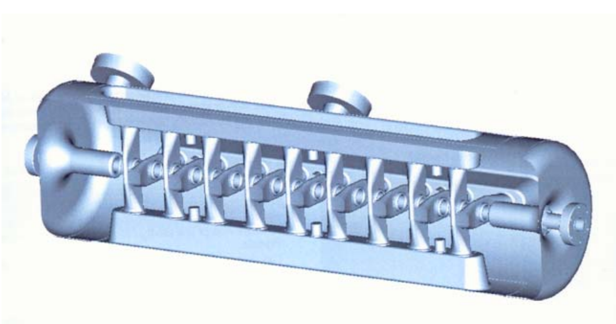

Figure 1: The 19-cell CH-prototype cavity.

Several cryogenic tests in a vertical cryostat have already been performed and an effective accelerating voltage of 3.8 MV in cw operation has been achieved [2].

The future challenge is to stabilize the resonance frequency of the cavity during operation. A detailed mechanical structure analysis of the cavity forms the basis for the design of a tuning device.

MECHANICAL ANALYSIS

The mechanical analysis of the CH-structure is mainly concerned with the description of the deformation under loads at liquid helium temperatures. Mechanical loads are either applied on the surface as the hydrostatic vacuum pressure inside the cavity or are initiated by controlled external forces. Every deformation results in a change of the eigenfrequency and can be used to tune the cavity. All loads have to be limited by fracture criteria to avoid a mechanical damage of the structure. The first experimental evidence of a frequency shift is observed by the cooling of the structure with results in a homogeneous contraction. If the cavity is unconstrained no additional stresses occur in the material. The measured changes in frequency can be compared with calculated values, obtained by uniformly scaling the model for the CST Microwave Studio [4] analysis according to temperature dependent contraction data for niobium [5]. Figure 2 shows the comparison, where the data points with error bars are related to the experiments and the black data squares show the simulation results.

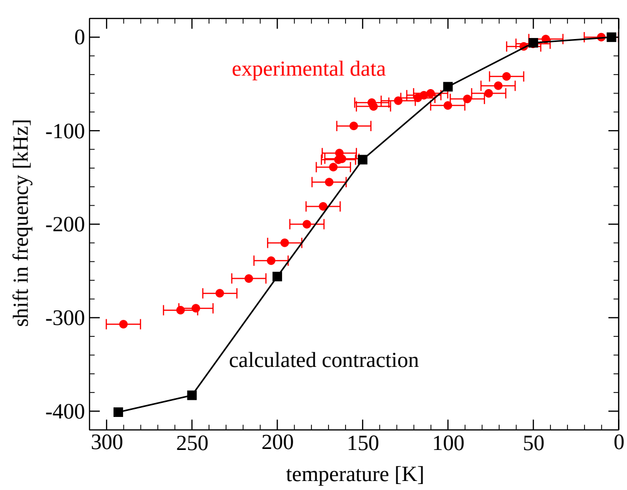

Figure 2: The shift in frequency during the cooling procedure.

For the tuning of the cavity the effect of an external force applied on the outer half drift tubes parallel to the beam axis is analysed. Since the body of the structure is quite rigid only the deformation of the end caps is considered. The FEM tool that has been used to solve the structure mechanical problem is called COMSOL Multiphysics [3]. The result of the simulation for a force of 4 kN is represented by the distribution of the von Mises stress σ_v that is defined by

$$\sigma_v := \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}}, \quad (1)$$

where $\sigma_1, \sigma_2, \sigma_3$ are the principal stresses.

Figures 3 and 4 show the deformed end caps from the outer and inner side of the cavity.

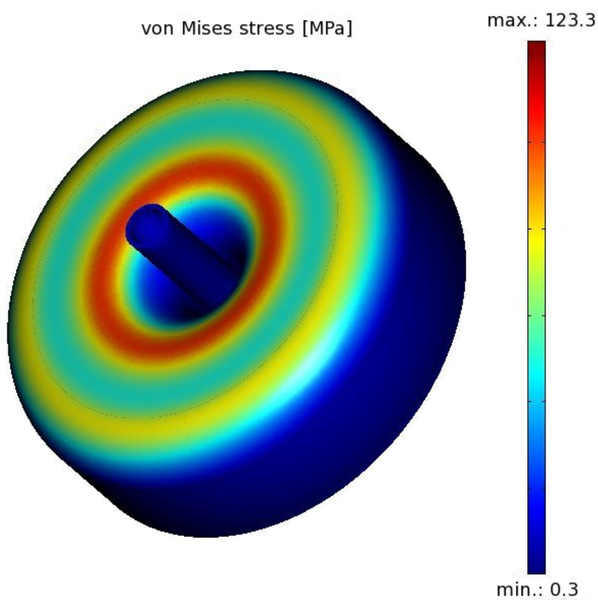

Figure 3: The deformed end cap from outside.

The red shaded regions depict the maximum values of the von Mises stress that are plotted in figure 5. A negative external force is obtained by pulling both ends of the structure. The minimum of the von Mises stress is not reached at zero external force, because it is assumed that the cavity is under vacuum and the atmospheric pressure applies on the outer surface.

In order to calculate the shift in frequency we replace the undeformed end caps in the model for the CST Microwave Studio simulation with the deformed ones for several values of the external force and redo the eigenmode analysis with the same mesh parameters. The main effect that causes tuning is the change in capacity due to a variation of the end gaps. The result of this analysis is presented in figure 6.

There is further experimental evidence for a shift in frequency due to a change in external pressure (figure 7) and a variation of the squared electric field strength E_a (figure 8).

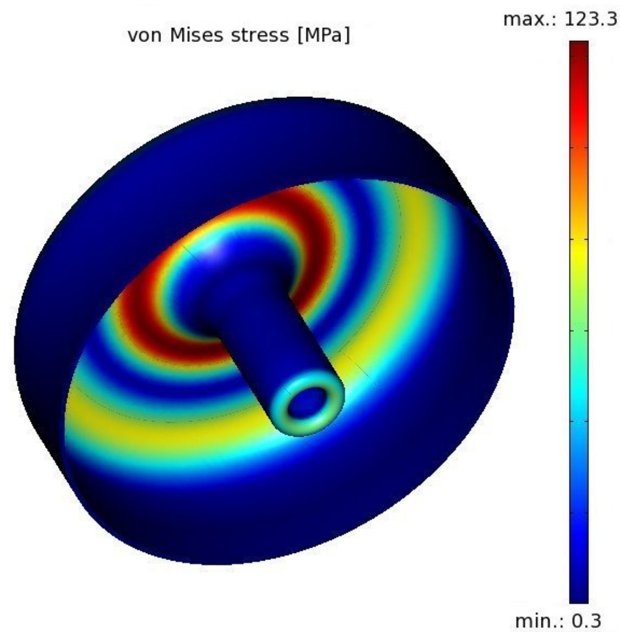

Figure 4: The deformed end cap from outside.

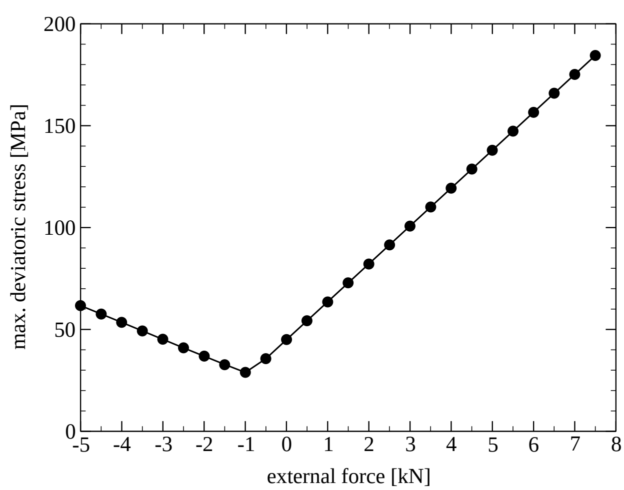

Figure 5: Maximum values for the von Mises stress.

TUNER CONCEPT

Two different time scales have to be considered. On the one hand a rather slowly acting mechanical tuner is necessary in order to achieve the preselected radio frequency of operation and on the other hand a fast piezo device will be used to respond to small fluctuations in frequency. Mechanical vibrations of the structure can for example be the origin of such small deviations in frequency. Further cryogenic tests will be performed in an existing horizontal cryostat that has to be adopted for that purpose. A schematic picture of this cryostat is given in figure 9.

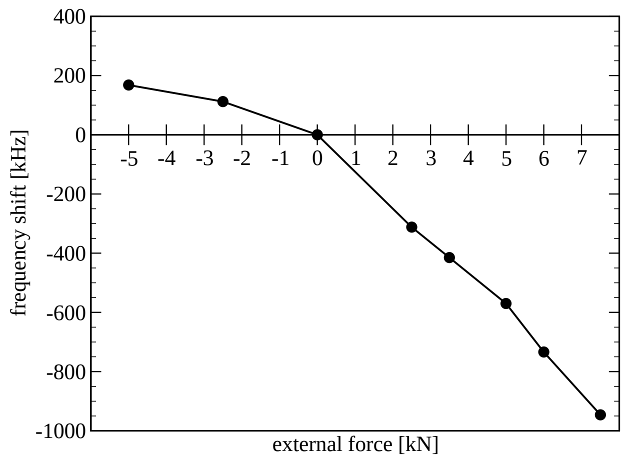

Figure 6: Shift in frequency due to external force.

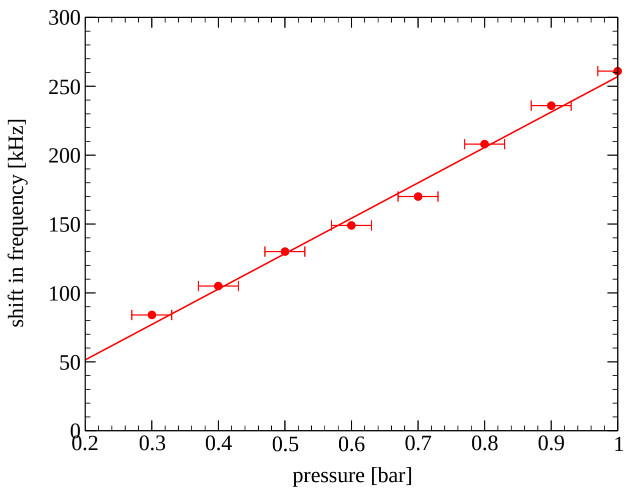

Figure 7: Shift in frequency due to change in external pressure.

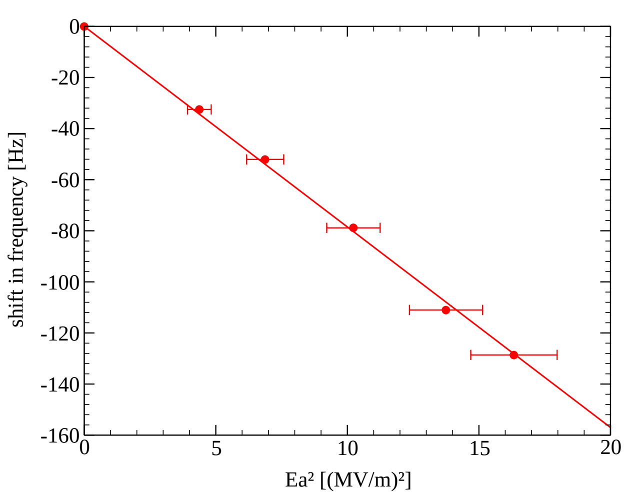

Figure 8: Shift in frequency due to change in electric field strength.

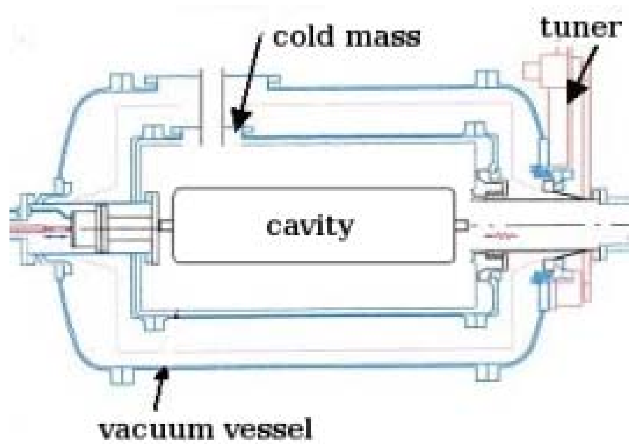

Figure 9: The horizontal cryostat with tuner and cavity.

REFERENCES

[1] U. Ratzinger, R.Tiede, Status of the HIIF RF linac study based on the H-mode cavities, Nucl. Instr. and Meth. A 415(1998) pp. 229-235

[2] H. Podlech et. al., First Cryogenic Test of the Superconducting CH-Structure, Proc. of the EPAC06, 2006, Edinburgh, UK

[3] www.femlab.de

[4] www.cst.com

[5] Handbook on Materials for Superconducting Machinery, Metals and Ceramics Information Center Battelle, 1977, Columbus Laboratories