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CHARACTERISTICS AND FABRICATION OF A 499 MHZ SUPERCONDUCTING DEFLECTING CAVITY FOR THE JEFFERSON LAB 12 GEV UPGRADE*

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Abstract

A 499 MHz parallel bar superconducting deflecting cavity has been designed and optimized [1,2] for a possible implementation at the Jefferson Lab. Previously the mechanical analysis [3], mainly stress, was performed. Since then pressure sensitivity was studied further and the cavity parts were fabricated. The prototype cavity is not completed due to the renovation at Jefferson Lab which resulted in the temporary shutdown of the electron beam welding facility. This paper will present the analysis results and facts encountered during fabrication. The unique geometry of the cavity and its required mechanical strength present interesting manufacturing challenges.

INTRODUCTION

The previous stress analysis of the cavity indicated some area of the cavity is subject to plastic deformation resulted by the local stress exceeding the material yield strength [3]. The weak area has a complex geometry where it is hard to attach the stiffeners. Therefore the part of cavity was machined to have greater thickness while the most of other parts were fabricated by conventional stamping. These parts are to be electron beam welded. A completed cavity will be tested for baseline frequency, pressure sensitivity and so on. Further simulation was performed and the results will be compared to the cavity test results. The comparison data between the simulation and cavity tests will yield valuable information which enables one to save time and cost in making cavities to achieve the goals.

PRESSURE SENSITIVITY

Many aspects of cavity characteristics are studied with undeformed cavity volume. When the cavity is evacuated the external pressure deforms the cavity. The external pressure can be atmospheric or liquid helium pressure when it is enclosed in the helium vessel. At any rate this changes the inside volume of the cavity which shifts the target frequency. To simulate this effect the following procedure was performed using ANSYS.

1. The 3D model was constructed including the vacuum inside the cavity. Figure 1 shows the meshed model of the Niobium cavity and the vacuum sharing the contact surface.
2. An artificial low modulus of elasticity (10^{-6} Pa) was assigned to the vacuum so there is no resistance to the cavity deformation.
3. The resonant frequency was calculated by ANSYS high frequency eigen-solver (Block Lanczos) before deformation.
4. The different value of external pressure was applied on the cavity outside surface.
5. The vacuum volume was deformed as the cavity deforms. The geometry of the deformed vacuum was extracted and the resonant frequency was calculated again.

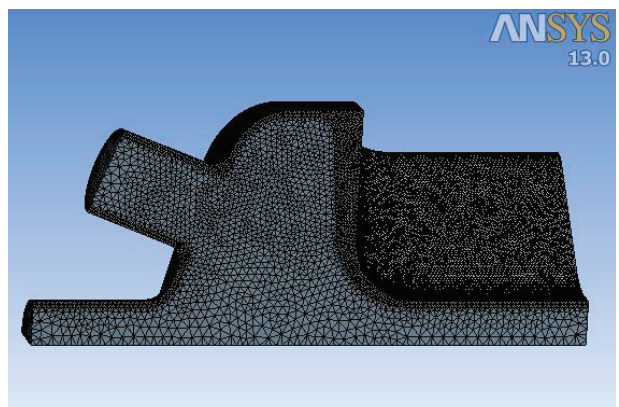

Figure 1: Mesh

The initial frequency under no deformation was found to be 498.03 MHz. It is lower than the target frequency 499 MHz because the cavity was scaled slightly bigger according to the thermal expansion coefficient of the Niobium. Since the target frequency 499 MHz has to be realized at the superconducting temperature 2-4K, the cavity fabricated at room temperature is accordingly larger.

There is also a small difference in initial frequency value between ANSYS and CST Microwave studio due to the different meshing. This difference was ignored because the study purpose was to see the frequency change by the external pressure.

The results show a linear relationship between the frequency and the pressure (Figure 2). This baseline cavity without added stiffeners has a pressure sensitivity of -1.59 Hz/Pa or -212 Hz/torr.

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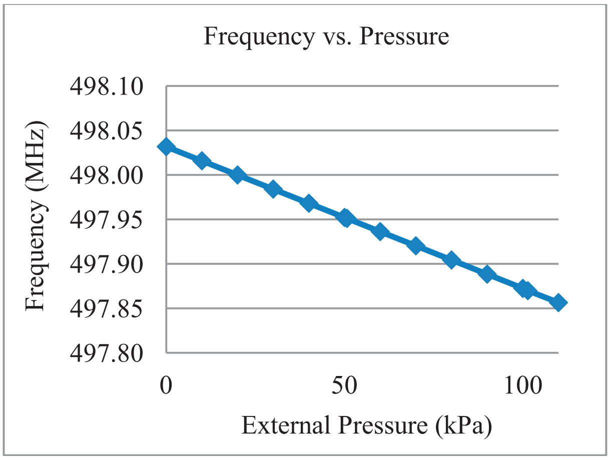

Figure 2: Pressure sensitivity

In case the cavity should be less sensitive to the pressure, placing stiffeners is expected. To identify the most effective surface to stiffen, the pressure on specific surface was removed while the rest of surfaces are still under 1 atm pressure. This is an artificial condition that is assumed to have a similar result as having stiffeners on the pressure removed area. Figure 3 shows the location of the surfaces and Table 1 shows the results.

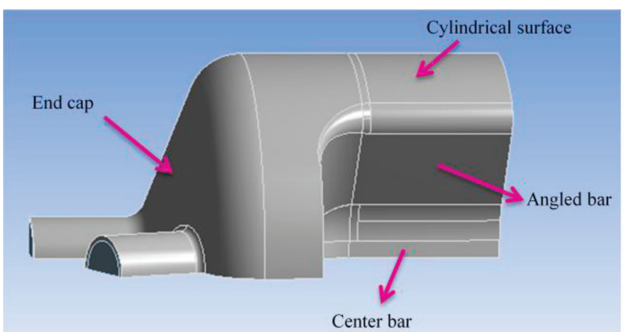

Figure 3: Pressure removed Surfaces

Table 1: Surface's Effect on Frequency Change

Pressure removed surface	Frequency change (MHz)
Cylindrical surface	-0.86
Angled bar surface	0.24
Center bar surface	0.04
End cap surface	-0.02

According to the simulation, to have the frequency after all mechanical preparation, mainly evacuation, as close as possible to the base frequency of undeformed cavity, stiffeners on the center bar and the end cap are most effective. In the model some stiffeners were added as shown in Figure 4 and the frequency shift was calculated to -120Hz/torr.

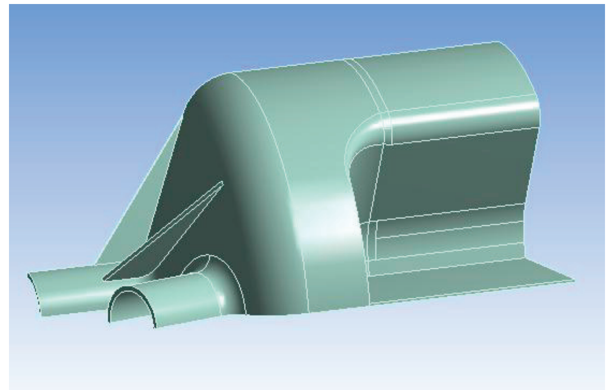

Figure 4: Added stiffeners

FABRICATION

The cavity is a combination of stamped and machined parts. A section of the cavity was machined to have larger thickness in the area where the stress analysis shows plastic deformation under 2.2 atm external pressure [3].

A set of copper parts were made first to verify the stamping dies and the computer numerical control (CNC) machine cutting profiles.

Center Shell

Four half shells (Figure 5) were stamped using the same stamping die to make 2 welded shells. The weld edges were trimmed considering the weld shrinkage allowance and then electron beam welded. The edges where they meet the shoulder blocks were trimmed by electrical discharge machining (Figure 6).

Figure 5: Half shells before welding

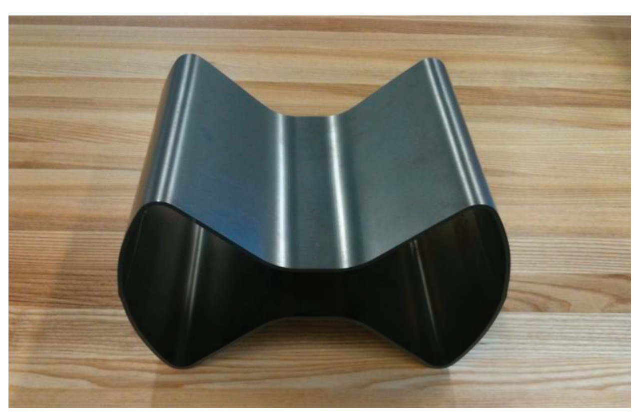

Figure 6: Welded and trimmed center shell

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Shoulder Block

The shoulder blocks (Figure 7) were machined in a CNC machine. Three-D model was directly fed to the CNC machine for this process. The shoulder block is a transition from the center shell to the circular end caps. The figure shows the both sides.

Figure 7: Shoulder blocks

End Caps

The end cap is a subassembly (Figure 8) which consists of an end cap, a beam port, and auxiliary ports. The end cap was stamped first and the beam pipe and flange assemblies were welded. The flanges are made of Niobium-Titanium alloy.

Figure 8: End cap subassemblies

Assembly View

Figure 9 shows how the parts will be put together. The parts are clamped together to measure the frequency as shown Figure 10. Depending on the measured frequency the parts will be further trimmed to meet the baseline frequency.

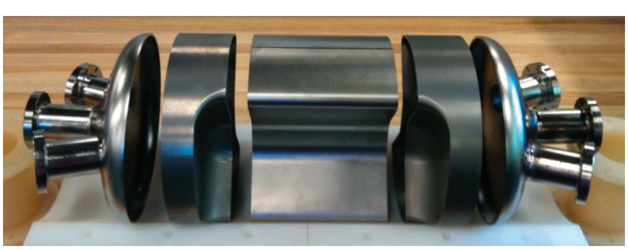

Figure 9: View of all parts

Figure 10: Assembly view

CURRENT STATUS AND PLAN

The frequency at the room temperature was measured to be 500.8 MHz [4]. The second welded center shell will be trimmed to a longer length to achieve the baseline frequency of 498 MHz. The final assembly is on hold until Jefferson Lab's electron beam welding facility is re-opened. In the meantime, an electropolish is planned before the final welding. The electropolish procedure is being laid out and the fixtures are being fabricated. A variable coupler is in the final assembly process.

It is planned that the stiffeners will be added after the cavity assembly welding and the cavity testing so the effect of the stiffeners is well understood.

ACKNOWLEDGEMENTS

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