CONCEPTUAL ENGINEERING DESIGN OF A BUNCH ROTATION CAVITY FOR A PION PRODUCTION AND CAPTURE EXPERIMENT

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Abstract

A conceptual design for a pion bunch rotator cavity has been performed. The cavity is an integral part of a pion production target and capture system envisioned as an experiment on the AGS at Brookhaven National Laboratory in support of the Muon Collider Collaboration [1]. The design specification calls for a single gap cavity operating at peak fields of 6 MV/m, limited by available RF, and an RF frequency of approximately 71 MHz, a harmonic of AGS. The cavity is located directly following the capture and matching solenoids and must accommodate the decay solenoids within the reentrant noses of the cavity. These requirements place severe restrictions upon the physical structure of the cavity. This paper will present the engineering design and supporting RF, thermal, and structural analysis to achieve a mechanically stable cavity with good steady state and transient thermal and RF performance. In addition, design details and the approach to fabrication will be discussed.

1 INTRODUCTION

The scope of this task was to develop a concept for the 71 MHz Muon Collider Target Cavity that satisfied the top level requirements of:

1. Thermal, mechanical, and RF stability, and,
2. Conform to the physical space restrictions imposed by the magnet subsystem.

Figure 1 is a schematic of the target experiment showing the magnet system and cavity RF surface profile[2]. This was the starting point for the conceptual design effort. The W-C coils located inside the re-entrant noses of the RF cavity are sized for 2cm clearance between the RF surface and the coil structure. Likewise, the next pair of solenoids on either side of the cavity are approximately 5cm away from the RF surface. These were the primary physical constraints on the cavity. The cavity diameter was a free parameter, the only limit being the 3 meter centerline height above floor. Other cavity characteristics and requirements are given in Table 1.

2 MATERIAL CONSIDERATIONS

The choice of material for this initial conceptual configuration is 304L austenitic stainless steel. This choice was made based upon (1) the desirable structural properties, (2) good availability of many product forms, (3) availability of standard high vacuum flange products, and (4) the large industrial base that fabricates large welded structures in this material. The downside of this choice is the low thermal and electrical conductivity. These properties lead directly to the generous distribution of cooling in many channels over the surface, and the requirement for copper plating after final machining.

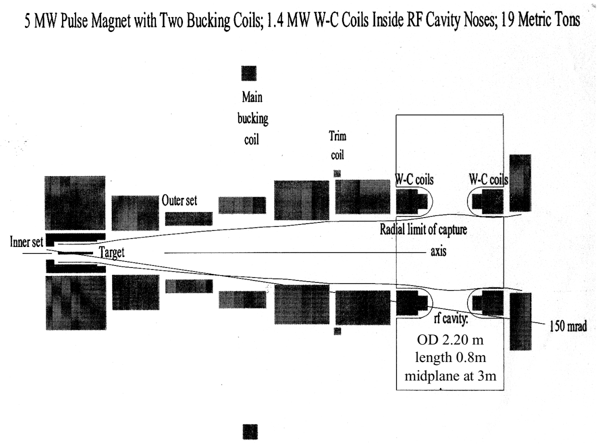

Figure 1 – Schematic of Target Experiment

Table 1 – RF Cavity Parameters & Requirements

Parameter	Requirement
RF Frequency	71.3 MHz
RF Power	6 MW Peak, 18 kW Avg.
Duty Factor	0.3% (200µs pulses @ 15 Hz)
Frequency Stability	+/- 100 kHz (range of tuner)
Required Ports	5 ports @ ϕ30cm, 6 ports @ ϕ2.75”
Mechanical Loads	Atmospheric and Gravity – No magnet loads
Mechanical Support	Self supporting (no support from magnets)
Thermal Control	Separate cooling circuit
Structural Materials	Non-magnetic

Other materials considered were aluminum alloy and copper alloy. Both of these materials or hybrids of these and other materials should be re-examined during preliminary design but they were judged to be significantly less attractive at this time for a variety of reasons.

3 GEOMETRY DEVELOPMENT

The first goal in design development was to refine the cavity shape to best optimize the structural performance within the given constraints. Clearly, domed end walls with stiffening provides the best stability against atmospheric loads. The limit on the depth of the dome was set so as to accommodate ports on the longitudinal centerline that are at least 12 inch diameter (~30 cm). It was decided to start with a shape that preserved a

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cylindrical center section with two detachable end walls. This was deemed to be a simple approach by separating the function of the end walls, which are free of any penetrations thereby maximizing the structural integrity, and the cylinder, which is a straight-forward double walled tank with various size ports distributed around the circumference. Figure 2 shows the original and revised cavity profiles. Figure 3 is an exploded view of the cavity.

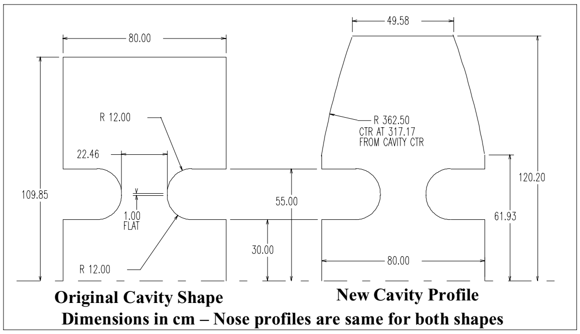

Figure 2 – Original & New Cavity Geometry

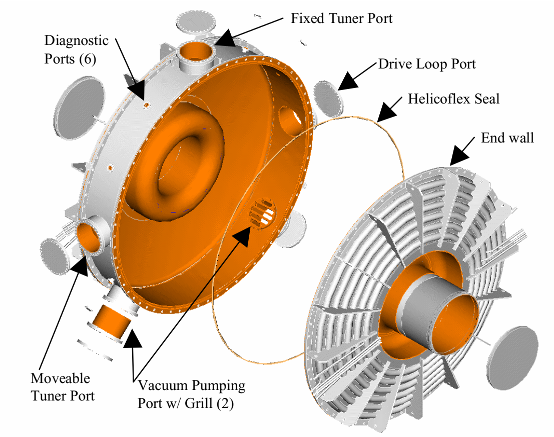

Figure 3 – Exploded View of RF Cavity

3.1 End Wall Design

The cavity end walls were designed using dimensions from standard domed tank heads conforming to shallow flanged and dished dimensions. The center of the dome is bored out to accommodate the re-entrant nose assembly that is then welded into position. The six “half-tube” coolant coils and the sixteen radial stiffeners are positioned and welded. The end wall is stress relieved prior to machining the final cavity surface dimensions.

The nose assembly is the most complicated portion of the cavity. This design was driven by the requirement for easy installation and removal of the solenoid magnets. This precluded the use of a coolant path that fed along the dome and returned along the beam tube because at some point the return lines would inhibit magnet movement. With stainless steel as the structural material, it was also important to have adequate cooling over a large fraction of the surface of the nose. The approach used employs machined coolant channels in the stainless steel and a thick copper electroform over the entire external surface of the re-entrant nose area providing conduction cooling. Figure 4 shows the end wall and the nose electroform.

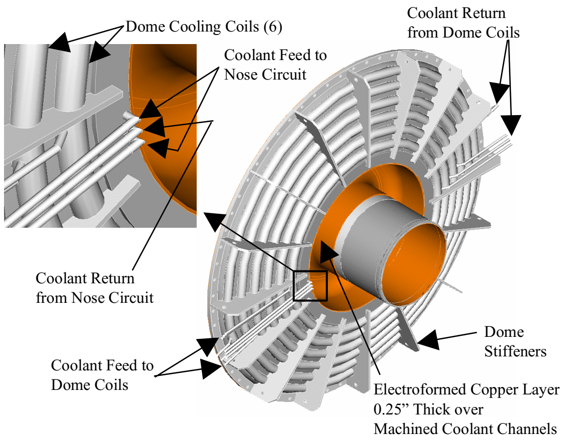

Figure 4 – End Wall & Nose Cooling Scheme

3.2 Cylindrical Cavity Barrel Design

The cavity barrel is a double walled vessel for the purpose of cooling. The cavity wall is .375 inches thick when finished and the 2-piece clamshell jacket is .25 inches thick. The water channel between them is .25 inches high. Other methods considered for cooling the wall were: (1) using discrete tubes much like the end dome or, (2) using dimple skin panels. Both of these approaches were discarded in favor of the double wall because it appears simpler when dealing with many ports penetrating the cavity. The double wall system will also provide better cooling to the port/cavity interfaces. Considering the low flow rates, we can use a single feed location at the bottom of the cavity and single return at the top and force the flow around the $\phi 30$ cm ports simplifying the plumbing and flow distribution system.

The double walled barrel (figure 5) is completely fabricated and welded to the end flanges prior to machining holes and installing the ports. First, the cavity wall is welded to the flanges followed by the two clamshell pieces of the jacket. The port holes are then machined and the ports installed. Internal welds will be ground smooth and helium leak checked. As with the end walls, the barrel will be thermally stress relieved prior to machining the final inside diameter and the flange faces.

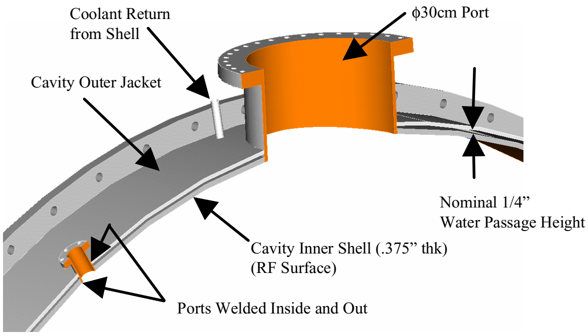

Figure 5 – Double Wall Cavity Cut-Away

The flanges on the barrel include a machined groove for a Helicoflex Delta seal that will serve as both the RF and vacuum seal.

4 THERMO-STRUCTURAL ANALYSIS

The cavity was analyzed for atnospheric pressure and thermal loading associated with RF losses during operation. As presented in Table 1, the average power dissipated on the cavity walls is 18 kW. Coolant is distributed to the different cooling circuits as shown in table 2 with an inlet temperature of 20º C and a total flow of 46 gallons per minute. Table 2 also indicates the average bulk velocity in the different circuits and the ΔT in the coolant.

Table 2 – Cavity Cooling Parameters

Component	**Flow Rate gal/min**	**Flow Velocity ft/s**	**Coolant Temp. Rise ºC**
Cavity Barrel	8.2	0.35	2.3
End Wall (2)	31.8 (2.65 per coil)	0.24	1.2
Nose Assy (2)	6.0	6.5	2.0
Total	46.0	N/A	1.5
Inlet Water Temperature – 20 C, Dissipated Power 18 kW			

Figure 6 shows the steady state temperatures, figure 7 shows the resultant displacements, and figure 8 shows the combined thermal and atmospheric stresses.

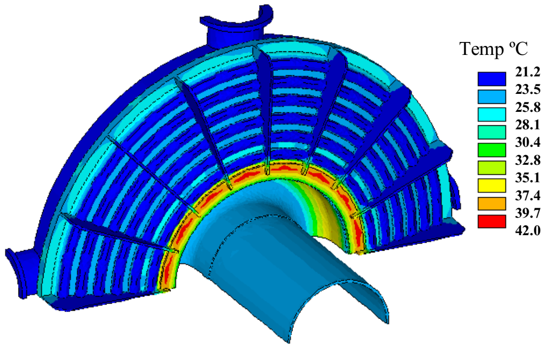

Figure 6 – Steady State Temperatures during Operation – 18 kW Avg. Power

The temperatures and stresses are quite reasonable for a stainless steel structure. The displacements and associated steady state Δf are also within limits.

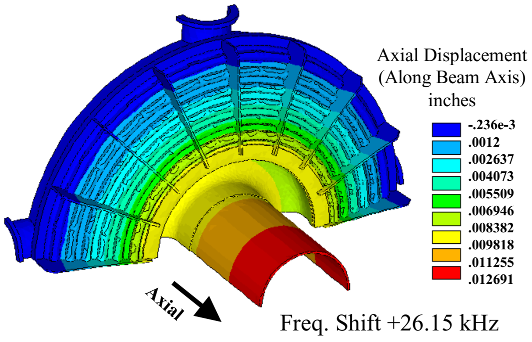

Figure 7 – Thermal Displacements and ΔF

A further analysis for transient thermal and RF behavior was run to ensure that the resonant frequency remained within the range of the moveable tuner at all times. Figure 9 shows the thermal transient of the cavity from a cold start at 18 kW avg. power (points identified in figure 8). Figure 10 then shows the resulting resonant frequency transient. The maximum Δf of +34.7 kHz is reached approximately 16 minutes into operation and the steady state Δf of +26.1 kHz is reached after more than 1 hour. These values are well below the limit of +/-100 kHz to remain within the bandwidth of the moveable tuner.

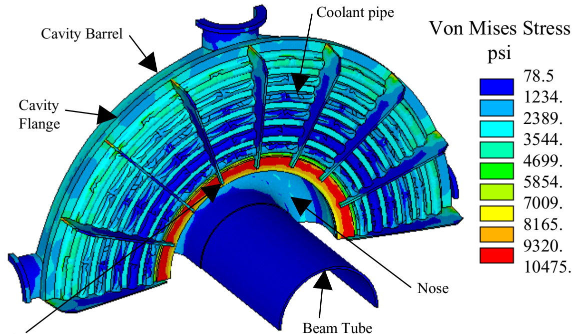

Figure 8 –Stress from Thermal & Pressure Loads & Points for Transient Temperature History

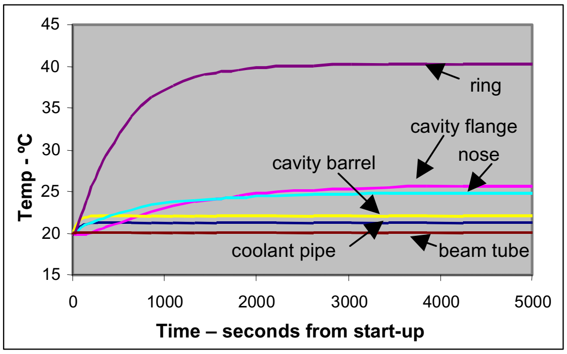

Figure 9 – Cavity Transient Temperature History

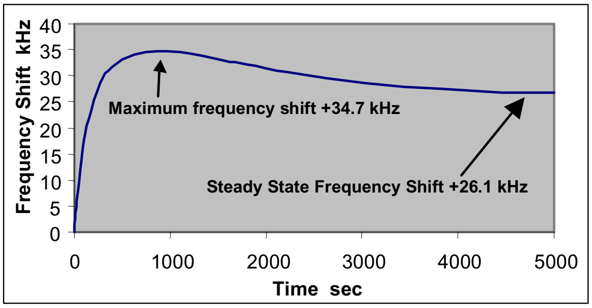

Figure 10 – Frequency Transient Due to Thermal Transient

5 CONCLUSION

A conceptual design has been developed for a large bore, single gap, 71 MHz cavity. The design meets all of the top-level requirements for mechanical, thermal and RF stability and has been developed to the point of producing conceptual fabrication drawings. The design drawings have been evaluated with ROM quotes for fabrication by industrial firms.

6 REFERENCES

[1] Ankenbrandt, et al., PRST-AB 2, 081001(1999), p.15-20

[2] Rose, J. “Conceptual Design of a Capture RF System for Muon Colliders,” these proceedings.