MECHANICAL DESIGN AND ANALYSIS OF SRF GUN CAVITY USING ASME BPVC SECTION VIII, DIVISION-2, DESIGN BY ANALYSIS REQUIREMENT*

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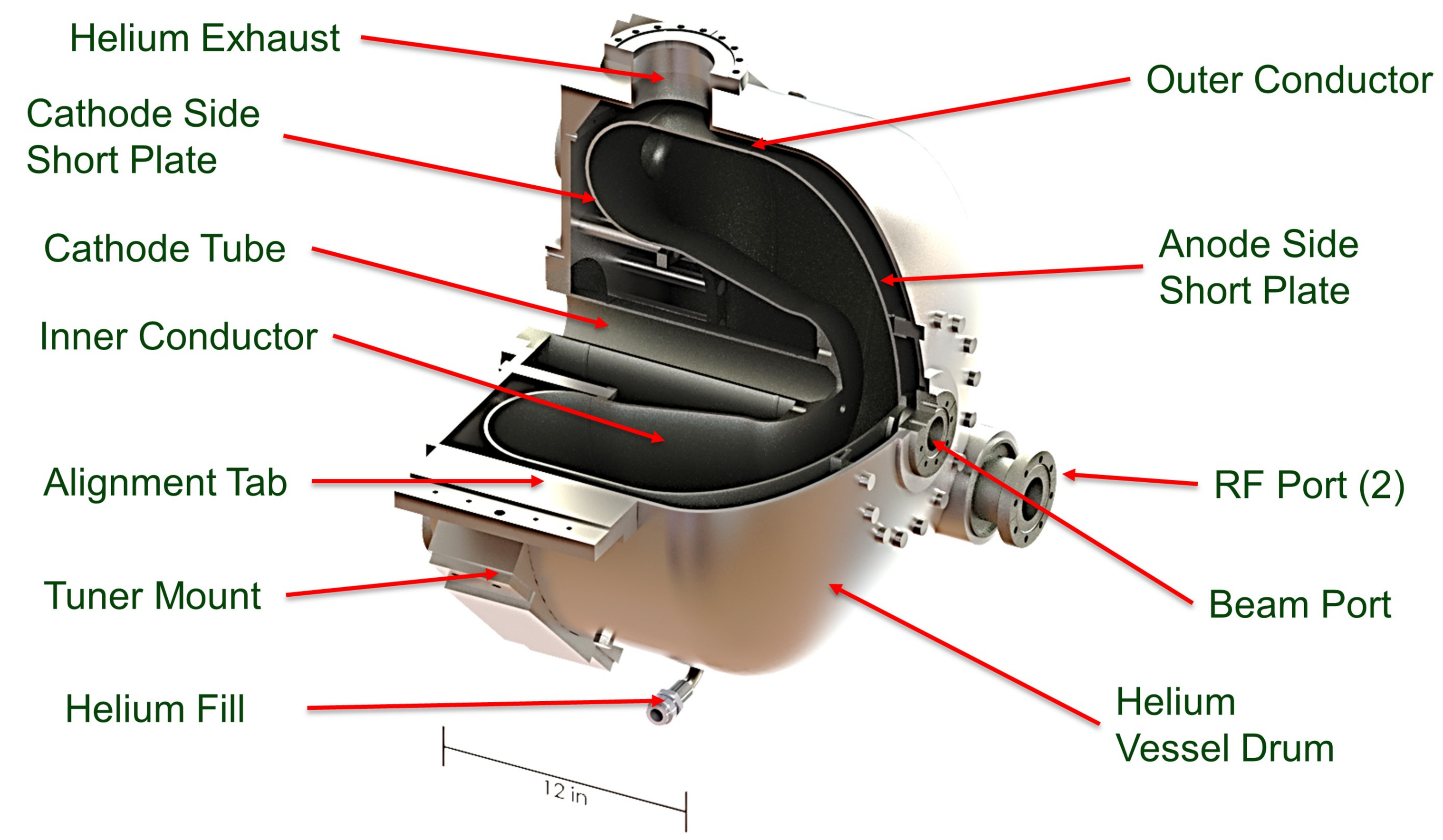
Abstract

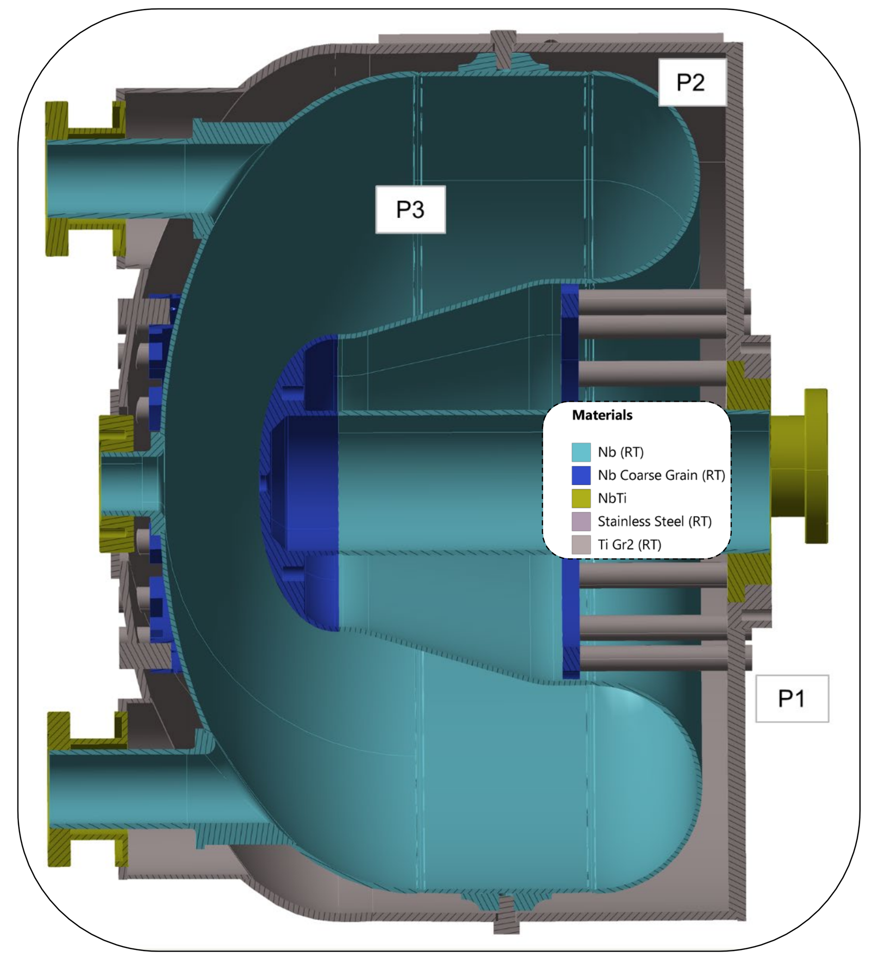
A prototype SRF gun is currently being designed at FRIB, MSU for the Low Emittance Injector of the Linac Coherent Light Source high energy upgrade at SLAC. This employs a 185.7 MHz superconducting quarter-wave resonator (QWR). The mechanical design of this cavity has been optimized for performance and to comply with ASME Section VIII, Div 2, Design by analysis requirements. This papers presents the various design by analysis procedures and how they have been adopted for the SRF gun cavity design.



SRF Gun cavity components (Inner cavity is Nb, outer vessel is Ti Gr-2)

RT	Gravity P2 = 0.227 MPa P1=P3=0 MPa	Warm Pressurization
RT	Gravity P2 = 0.227 MPa P1=P3=0 MPa T = 0.14mm	Warm Pressurization + Tuner Extension
4K	Gravity P2 = 0.41 MPa P1=P3=0 MPa	Cold Pressurization
4K	Gravity P2 = 0.41 MPa P1=P3=0 MPa T = 0.14mm	Cold Pressurization +Tuner Extension
RT	Gravity P1=P3=0.1 MPa P2= 0 MPa	Helium Space Leak Check
RT	Gravity P2=P1=0.1 MPa P3= 0 MPa	Cavity Space Leak Check
RT	Gravity P2=0.1 MPa P3= 0 MPa	Bare Cavity Leak Check

SRF Gun Cavity load cases (LC1 through LC4)



Design by Analysis Requirements

Protection Against Plastic Collapse:
- Elastic Stress Analysis Method
- ✔ Limit Load Analysis Method
- Elastic Plastic Stress Analysis Method

Protection Against Local Failure:
- ✔ Elastic Stress Analysis
- Elastic Plastic Analysis

Protection Against Collapse From Buckling:
- ✔ Bifurcation Buckling using Elastic Stress Analysis
- Bifurcation Buckling using Elastic Plastic Stress Analysis

Protection Against Failure From Cyclic Loading:
1. Fatigue Analysis
2. Ratcheting Analysis

Protection Against Plastic Collapse: Limit load analysis

Temp	Load Case	Design Load Combination	Convergence
RT	LC1	1.5(P2+Gravity)	Yes
RT	LC2	1.3(P2+Gravity+T)	Yes
4K	LC3	1.5(P2+Gravity)	Yes
4K	LC4	1.3(P2+Gravity+T)	Yes

Protection Against Local Failure

T	Load Case	Design Load Combination	$\sigma_1+\sigma_2+\sigma_3$ MPa	4S MPa	$\sigma_1+\sigma_2+\sigma_3$ <4S
RT	LC1	P2+Gravity	<160	160	Yes
RT	LC2	P2+Gravity+T	<160	160	Yes
4K	LC3	P2+Gravity	341	845	Yes
4K	LC4	P2+Gravity+T	333	845	Yes

Protection against Collapse from Cyclic Loading

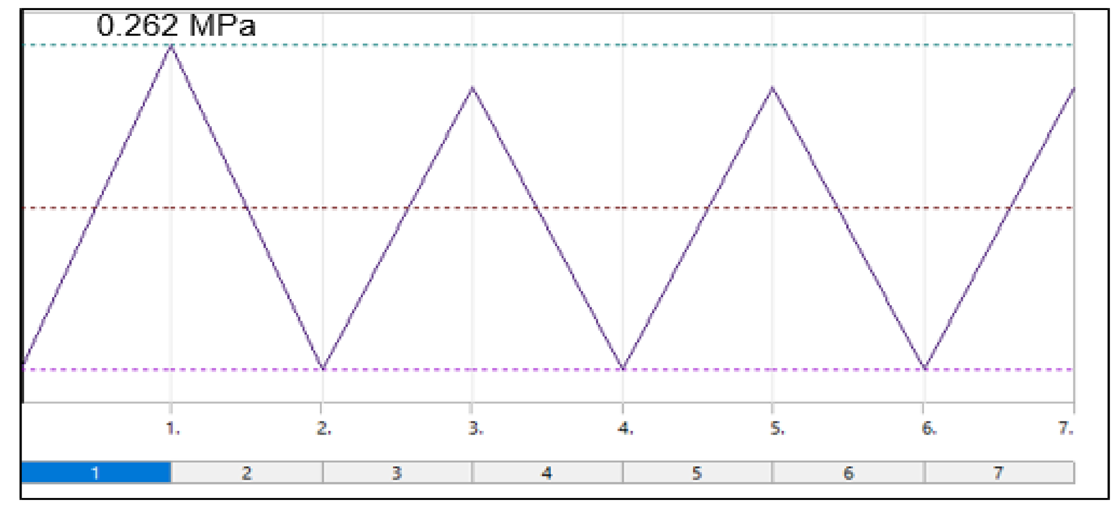
Fatigue Assessment

Type of cycle	Number
$N_{\Delta FP}$	33
$N_{\Delta PO}$	0
$N_{\Delta TE}$	66
$N_{\Delta Ta}$	33
$N_{\Delta Tuner}$	300
Total Cycles	432

$$N_{\Delta FP} + N_{\Delta PO} + N_{\Delta TE} + N_{\Delta Ta} + N_{\Delta Tuner} \leq 1000$$

The results of the screening criteria (Method A), show that the cavity has less total cycles during its lifetime than the screening criteria, therefore requiring no fatigue analysis

Ratcheting Assessment



MAWP = 0.227 MPa varied
Tuner Displacement = 0.14mm varied
First Load Step pressure = 1.15 * MAWP = 0.262 MPa
Gravity load included in all load steps

Analysis shows that there is no change in dimension between the last and next to last cycles (load cases 5 and 7), demonstrating convergence. This indicates that the structure has an elastic core and no permanent change in overall dimensions

Protection against Collapse from Buckling

Temp	Load Case	Design Load Combination	Load Multiplier
RT	LC1	P2+Gravity	11.2
RT	LC2	P2+Gravity+T	11.16
4K	LC3	P2+Gravity	7
4K	LC4	P2+Gravity+T	6.9

For bifurcation buckling analysis, a minimum design factor of ΦB =2/βcr is used as per the code. For unstiffened and ring stiffened cylinders and cones under external pressure β_{cr}= 0.80, or Φ_B = 2.5. All of the load multiplier are more than the required value of Φ_B = 2.5

Summary

- Structural analysis of SRF Gun cavity and supporting helium vessel design shows that it meets the ASME BPVC, Section VIII, Div. 2, Part 5
- Nb yield strength data before and after bake out, confirmed by testing
- FEA model includes wall thinning effects due to forming and etching
- Weld joints developed as per ASME BPVC Sec VIII, Div. 1

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This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, operated by Michigan State University, under Award Number DE-SC0000661.

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