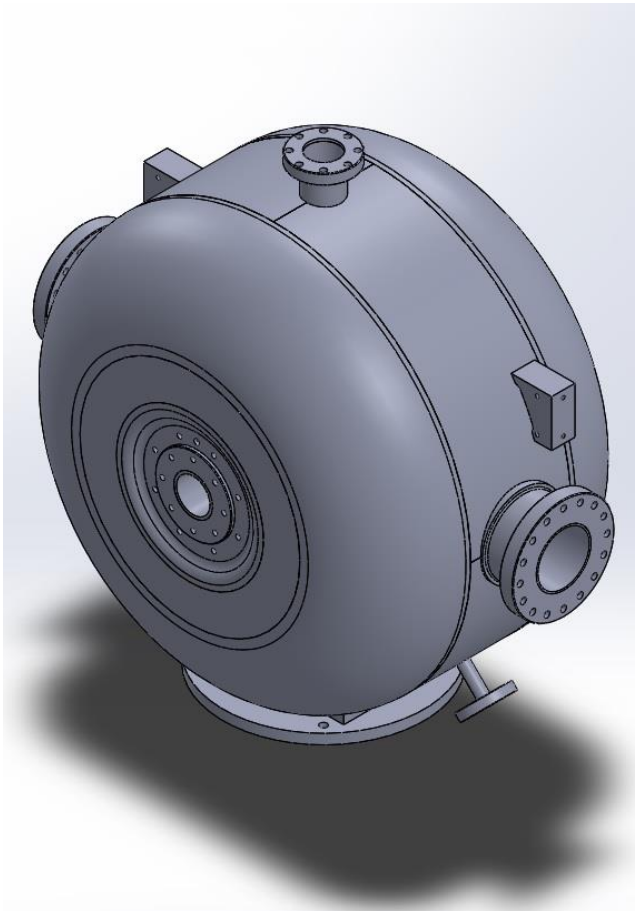
Engineering Design and Fabrication Process of SSR1/2 SC Cavity

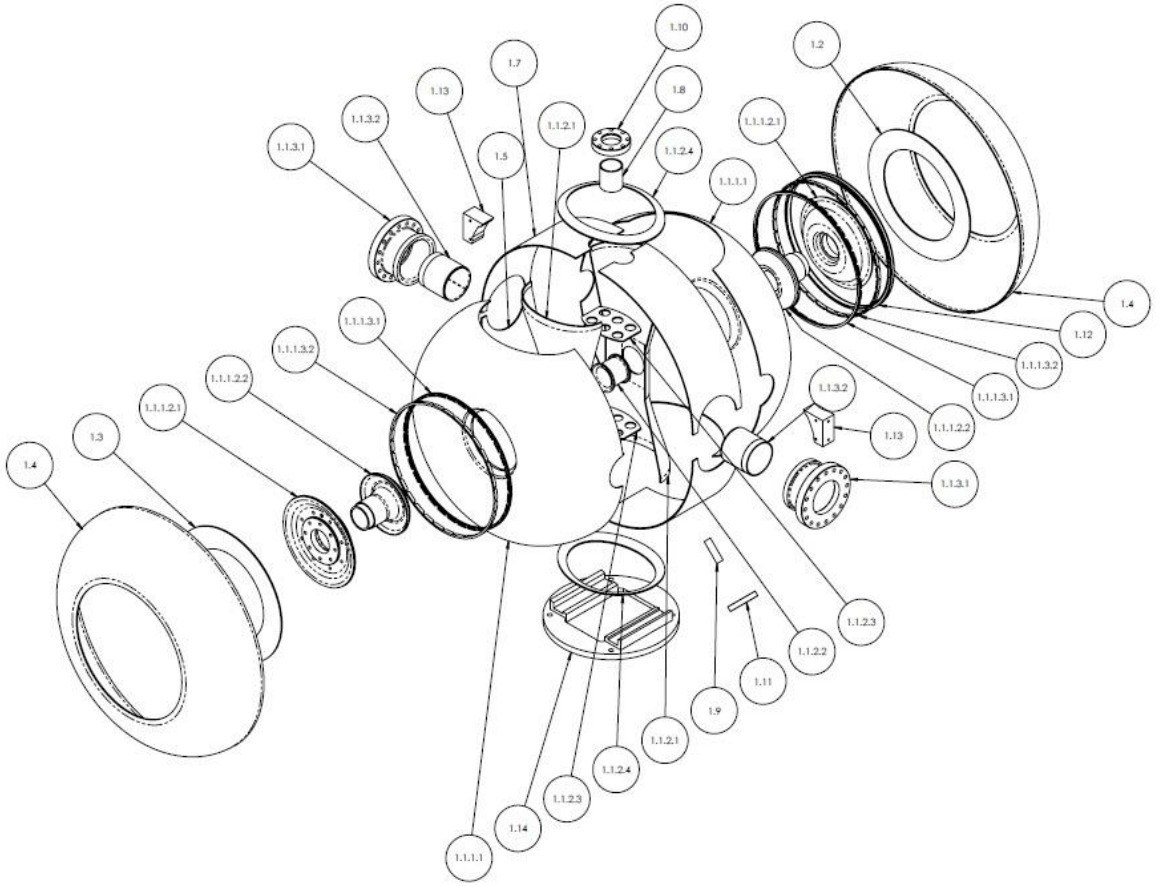
Myung Ook Hyun / SCL Development Team

2023.03.01.

SSR1 Cavity Design (TRIUMF)



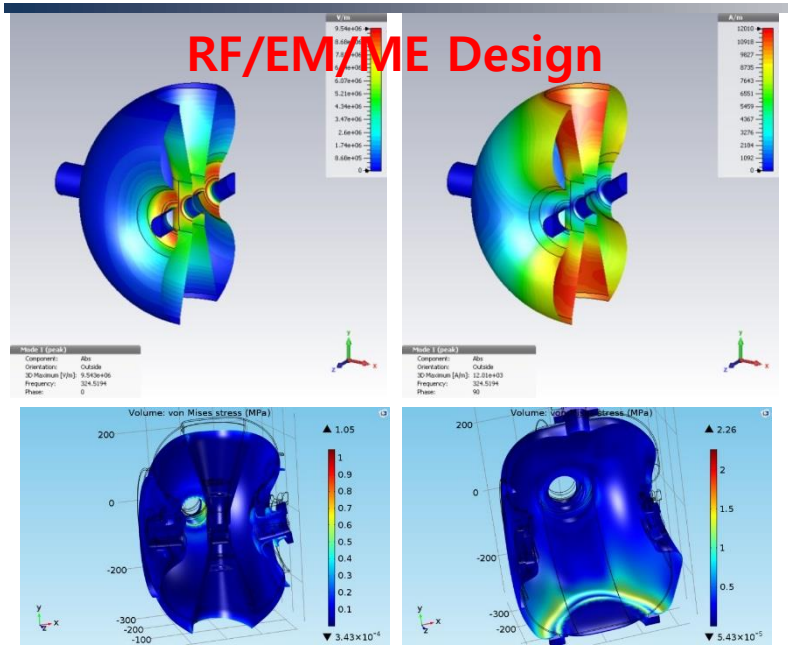
SSR1 3D Model



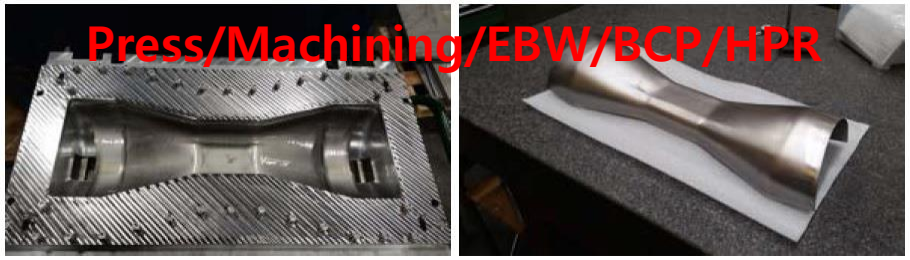
SSR1 Exploded View

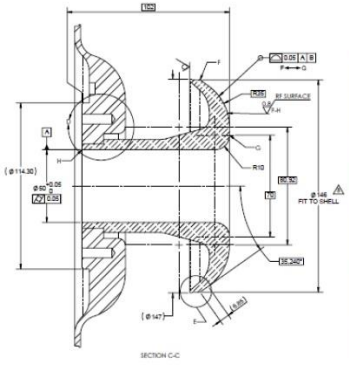
SSR1 Cavity Prototype (TRIUMF)

RF/EM/ME Design



Press/Machining/EBW/BCP/HPR

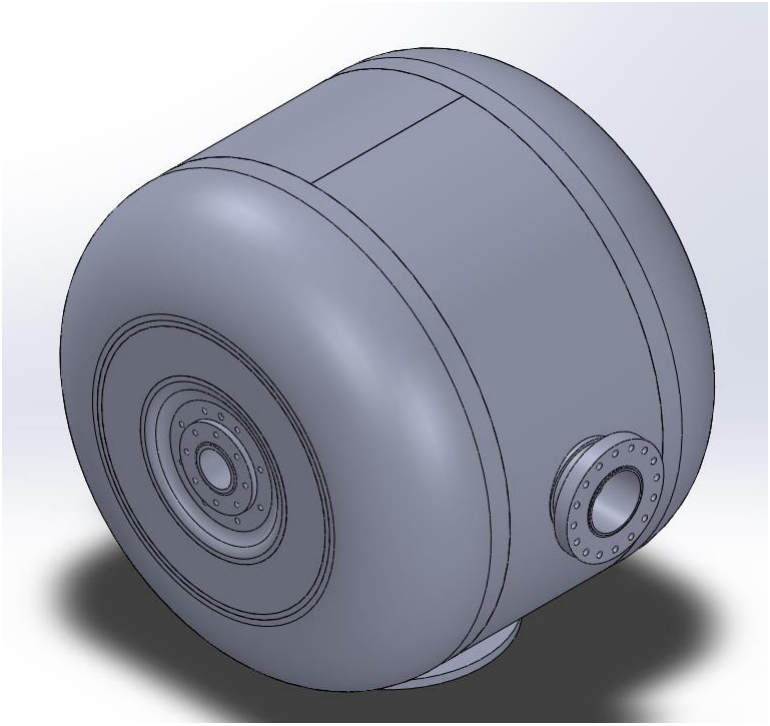




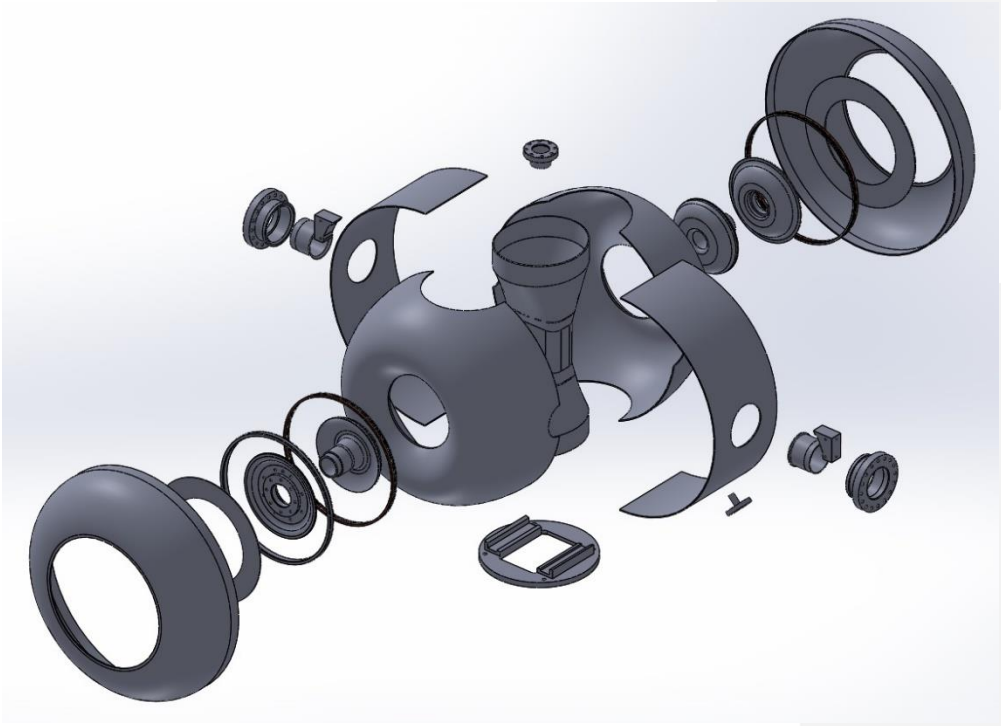
Jacketing

Proceeded By TRIUMF

SSR2 Cavity Design - Layout



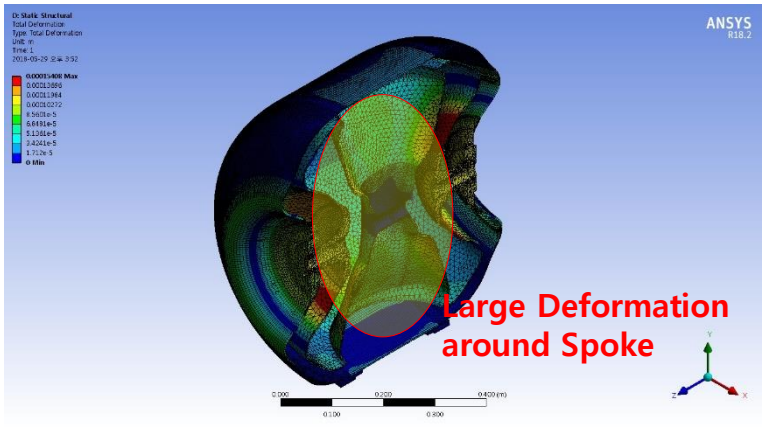
SSR2 3D Model

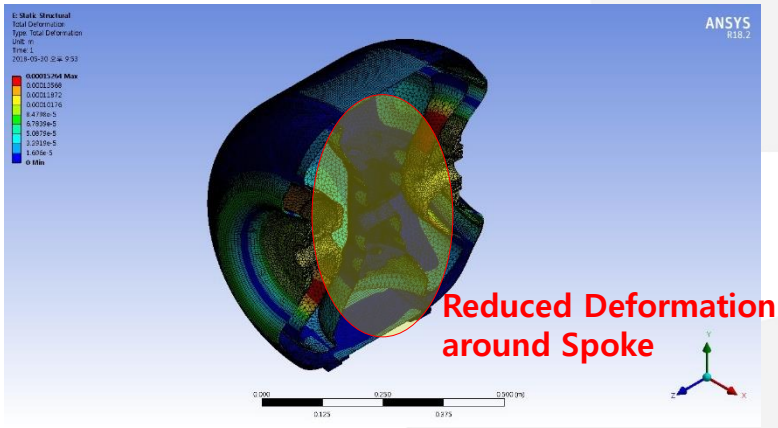


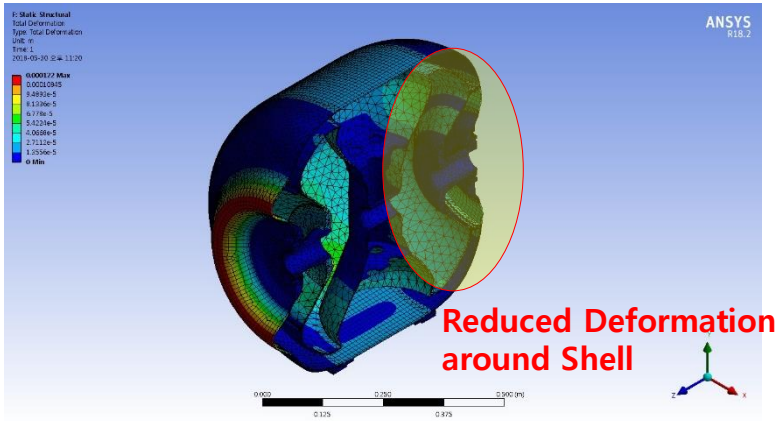
SSR2 Exploded View

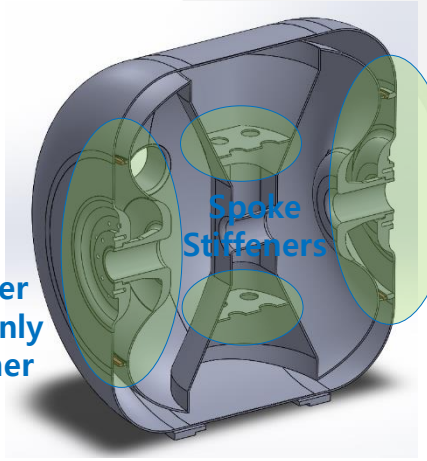
- SSR2 Superconducting Cavity
  - Cavity : 3T pure niobium (RRR 300 grade), single spoke, 0.51 beta, 325MHz, bulk machining beam port, stiffening ring and spoke stiffener for structural reinforcement, vacuum braze at every ports and flanges, EBW for weldment attach, beam port trimming for frequency adjustment
  - Jacket : 3T STS316L, 1.3 bar pressure vessel design (ASME Section-2 Part-D Subpart-1) , liquid helium volume 51.32L (33.05L for SSR1), GTAW for weldment attach, transition ring for stiffening ring interface

SSR2 Cavity – Mechanical Analysis







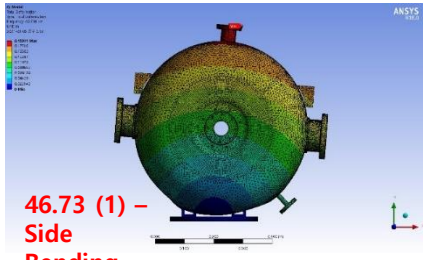


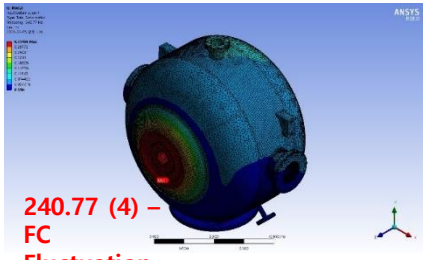
- SSR2 SC Cavity Mechanical Design
  - Before applying spoke stiffeners, spoke deformation/stress is quite large due to helium pressure. After applying spoke stiffeners at the upper and lower side of spoke, deformation/stress is reduced.
  - Still shell deformation/stress is over yield strength so that we applied stiffener rings at the front/rear side of shell surface. After applying stiffener rings, deformation/stress of shell is reduced.

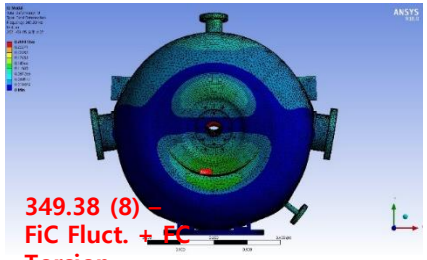
SSR1 Cavity Design – Mode Analysis

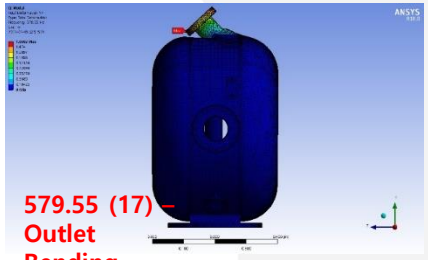
SSR1 SC Cavity Harmonic Analysis

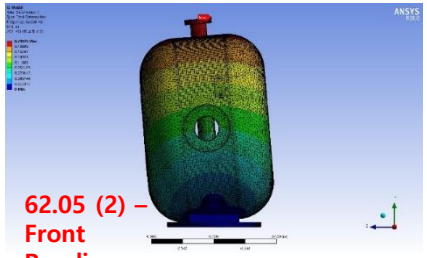
	ANSYS Simulation (Modal/Harmonic)	Vibration Test (Lateral Vibration)	Estimated Mode
1st Mode	46.73(1)/62.05(2)Hz	47.96Hz	Simple Bending Mode (Side/Front)
2nd Mode	240.77(4)Hz	234.6Hz	Free Cover Fluctuation Mode
3rd Mode	265.54(5)Hz	256.1Hz	LHe Inlet Bending Mode
4th Mode	349.38(8)Hz	349.2Hz	Fixed Cover Fluctuation + Free Cover Torsion
5th Mode	579.55(17)Hz	580.8Hz	LHe Outlet Bending Mode
6th Mode	710.06(23)Hz	737.3Hz	RF&LHe Outlet Ports Combined Bending Mode

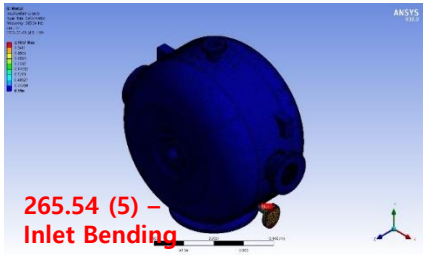


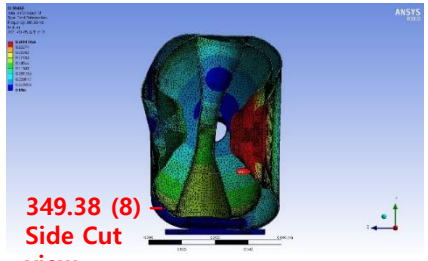


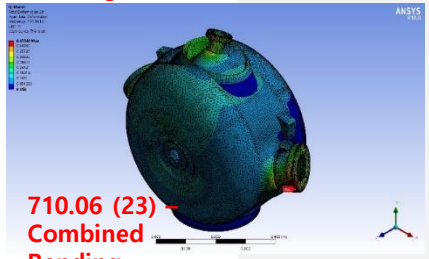






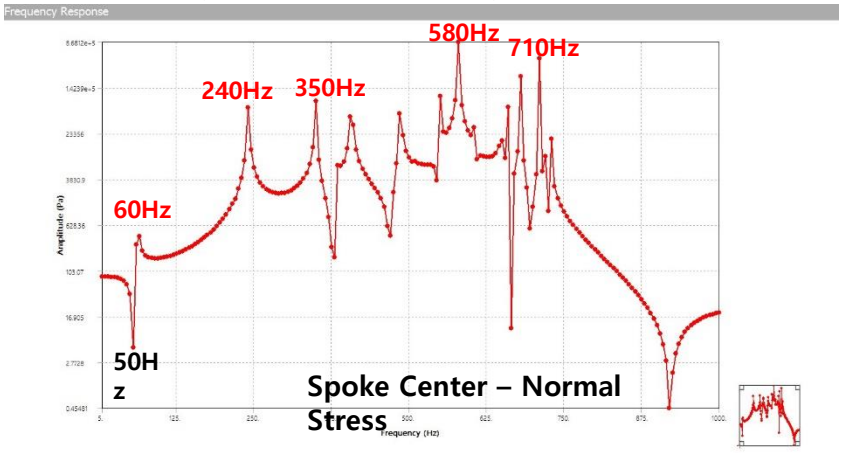


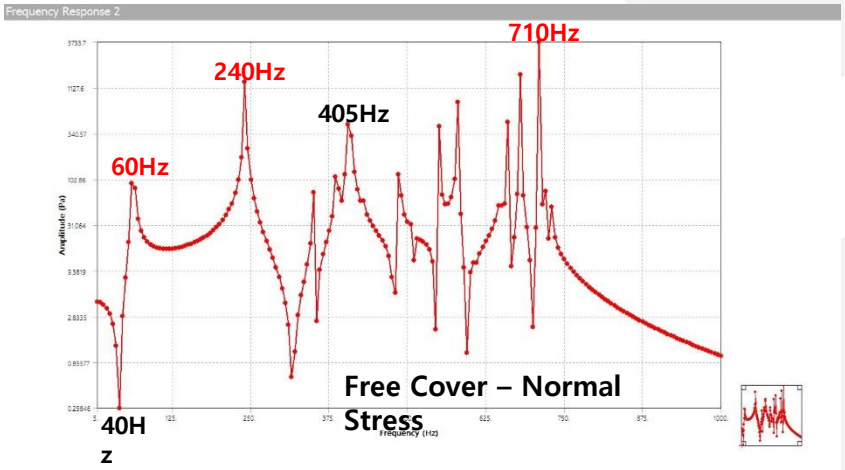


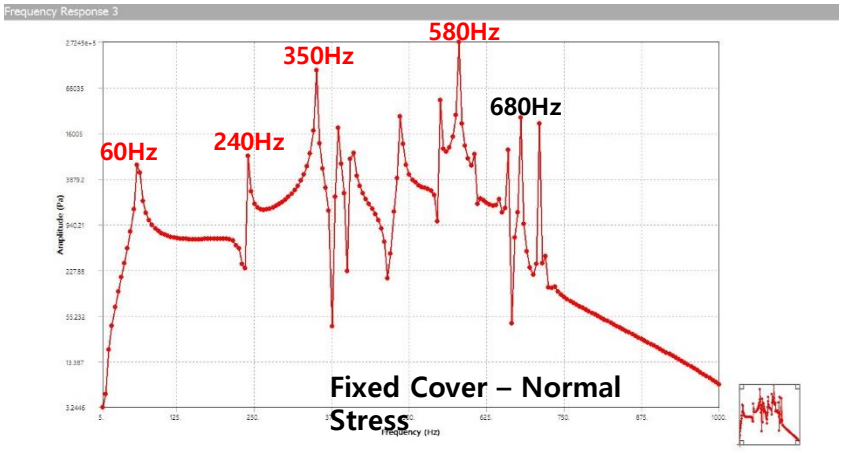


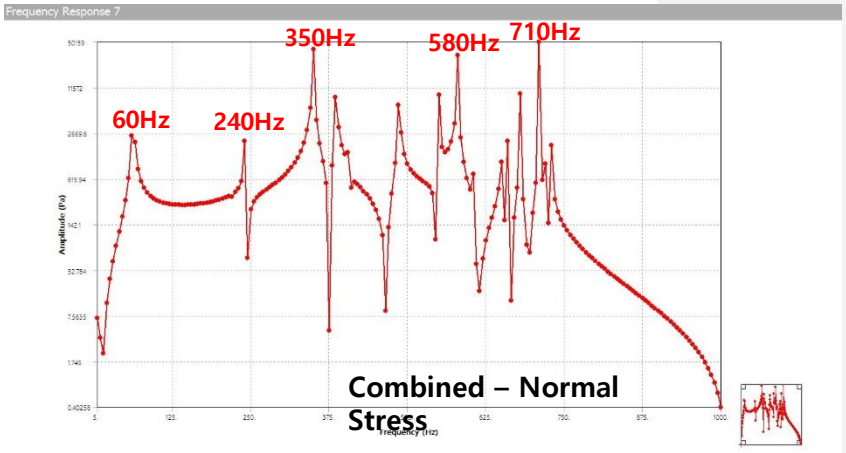
SSR1 Cavity Design – Modal Analysis

SSR1 SC Cavity Harmonic Analysis







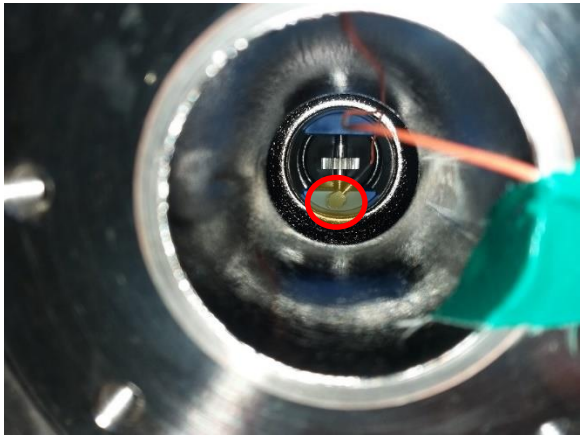


Common Modes : 60 / 240 / 350 / 580 / 710 Hz (Approximately)

SSR1 Cavity Design – Modal Analysis

SSR1 TR#1 Vibration Test



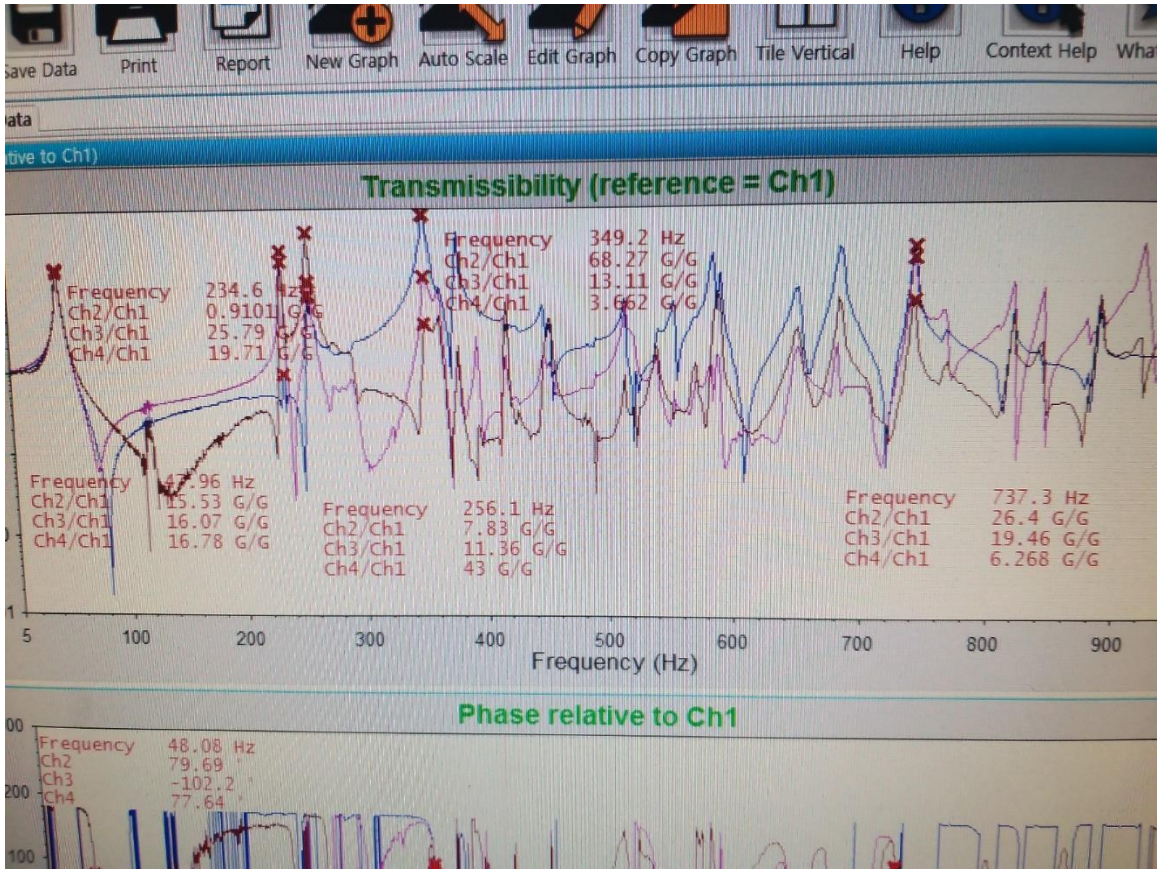
Vibration Test (done by KIMM)
- Test Condition
  .. 0.3G / 5 to 1000Hz Sweep
  .. Sensor : Spoke Center/Covers
- Lateral Vibration Machine

Spoke Fixture for Sensor
- Clamping Fixture (Lower Left)
- Installed by left/right thread

Purpose of Vibration Test
- Check the resonance of SSR1 dressed Cavity (around 42/240Hz)
- Draw the resonance map

SSR1 Cavity Design – Modal Analysis

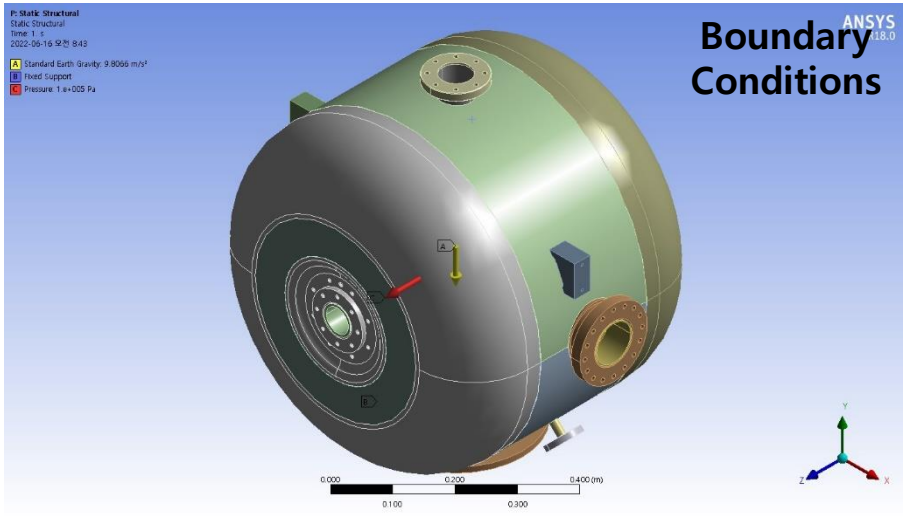
SSR1 TR#1 Vibration Test (2021. 03. 03~04)

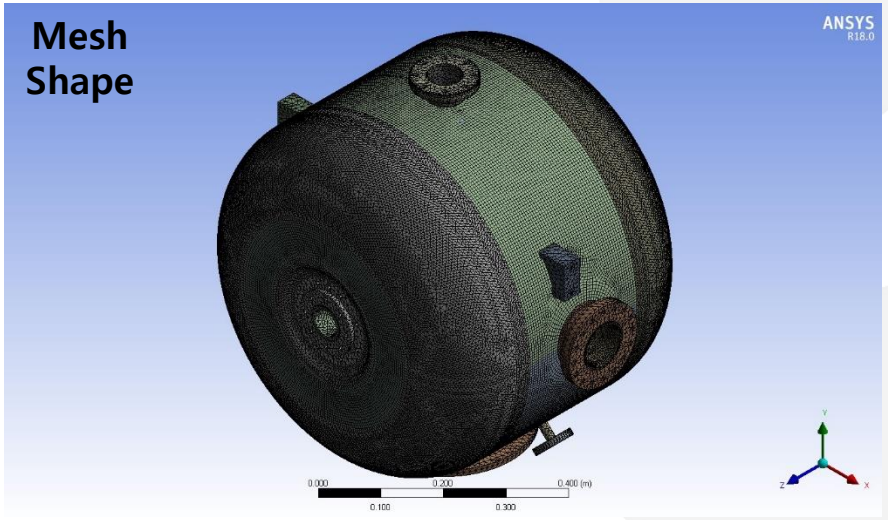


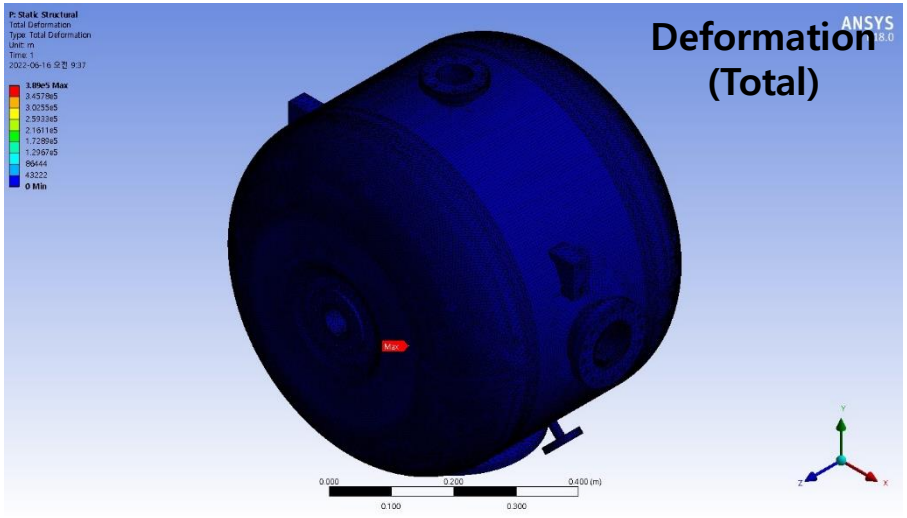
Test Results
- 1st Trial : Stopped due to high resonance @ 240Hz → Changed G-level from 0.5 to 0.3
- 2nd Trial : Done!
  .. 1st Peak : 47.96Hz
  .. 2nd Peak : 234.6Hz
  .. 3rd Peak : 256.1Hz
  .. 4th Peak : 349.2Hz
  .. 5th Peak : 580.8Hz
  .. 6th Peak : 737.3Hz

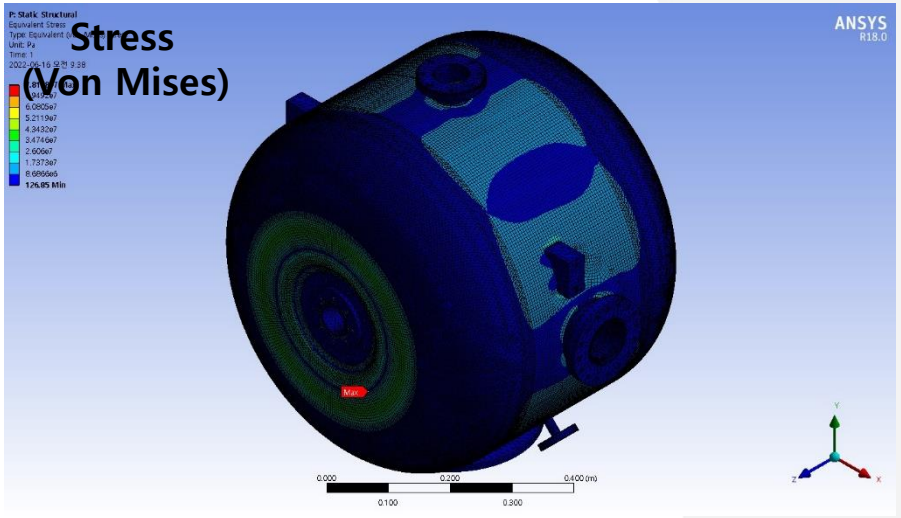
Consideration
- Main Peak : 1~4 peaks
- Need double-check : 5/6th peaks

SSR2 Cavity Design – Modal Analysis



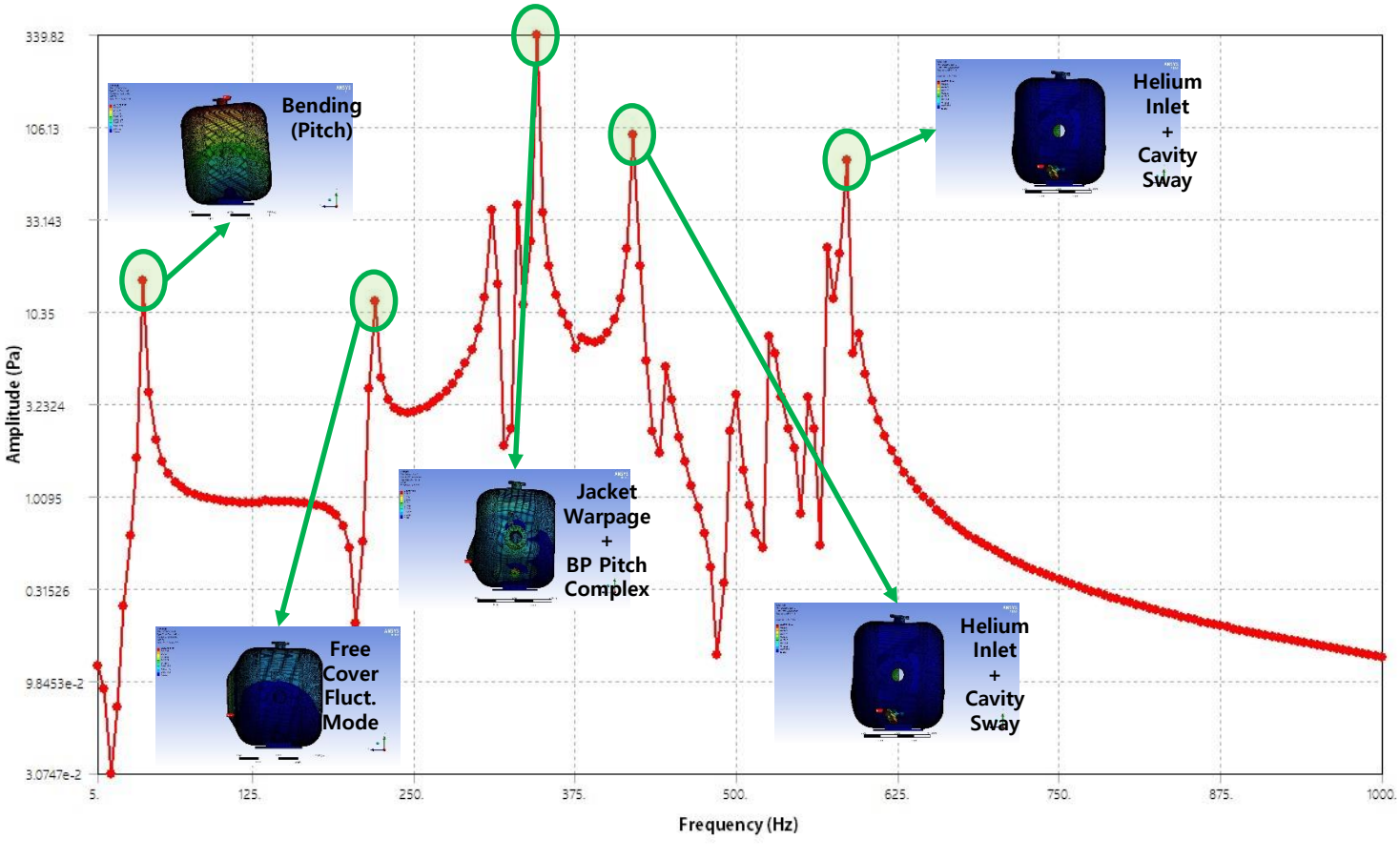


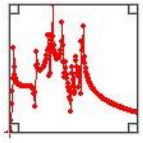




SSR2 Cavity Design – Modal Analysis

Frequency Response 7

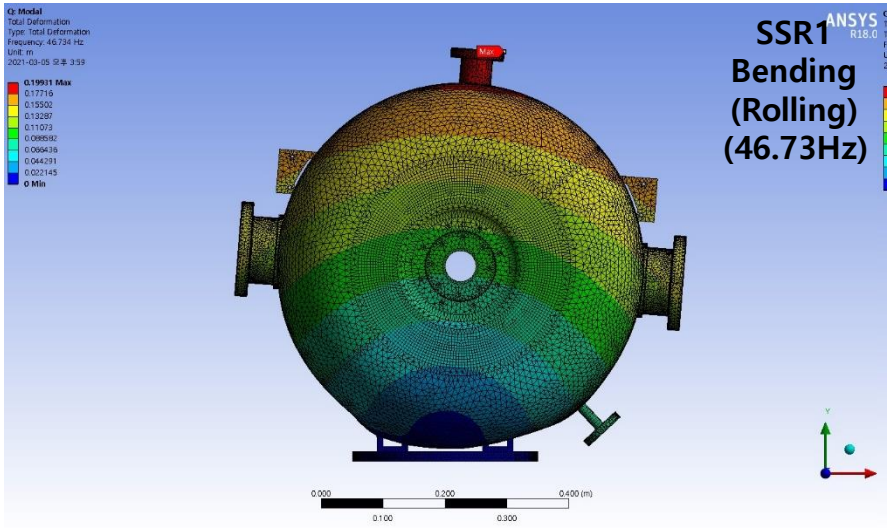




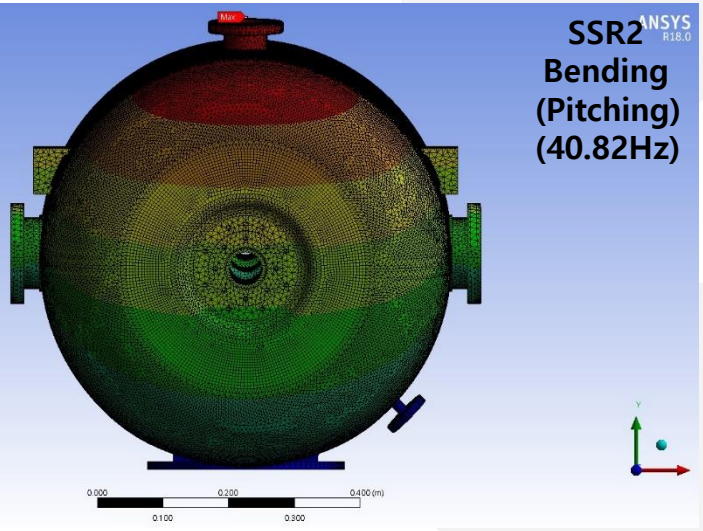
SSR2 Cavity Design – Modal Analysis

	SSR2 Mode	SSR2 Mode Estimation	SSR1 Mode	SSR1 Mode Estimation
1st	**40.82Hz**	**Simply Bending (Pitching)**	**46.73Hz**	**Simply Bending (Rolling)**
2nd	**218.21Hz**	**Free Cover Fluctuation**	**240.77Hz**	**Free Cover Fluctuation**
3rd	-	-	265.54Hz	Helium Inlet Bending
4th	**345.45Hz**	**Free Cover Torsion (Warpage)**	**349.38Hz**	**Free Cover Torsion (Fluctuate)**
5th	419.18Hz	Helium Inlet Bending	-	-
6th	**583.97Hz**	**Helium Outlet Bending**	**579.55Hz**	**Helium Outlet Bending**
7th	-	-	710.06Hz	Complex

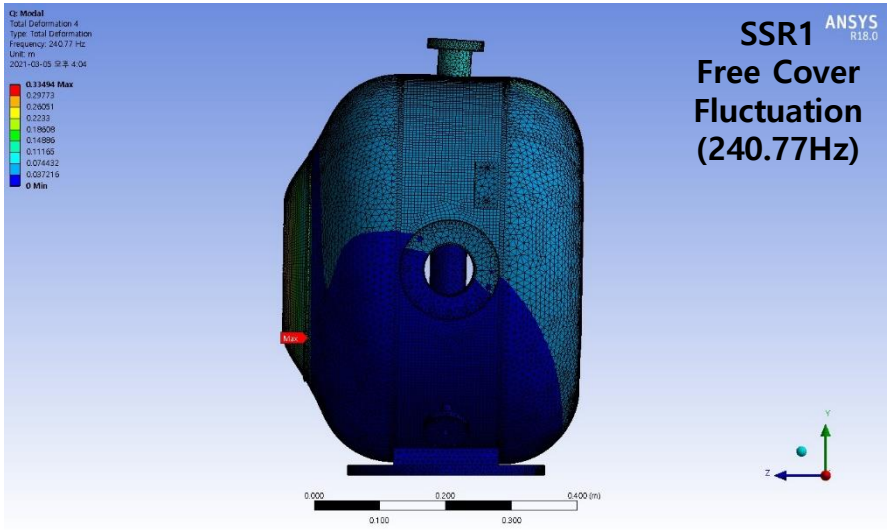
SSR2 Cavity Design – Modal Analysis



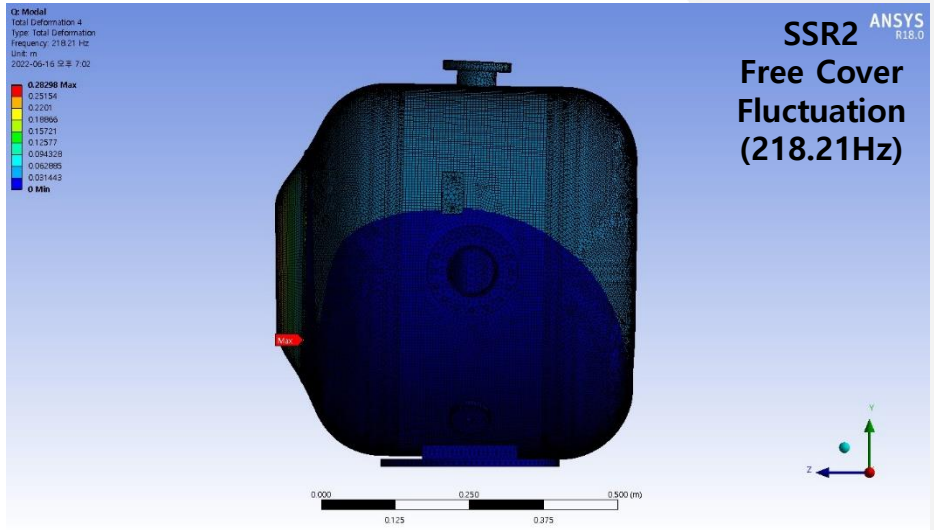
SSR1 Bending (Rolling) (46.73Hz)



SSR2 Bending (Pitching) (40.82Hz)

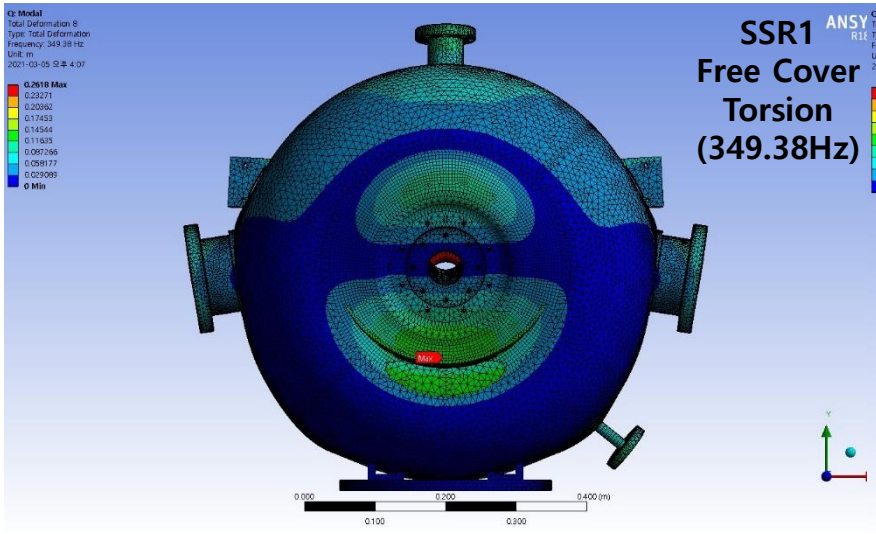


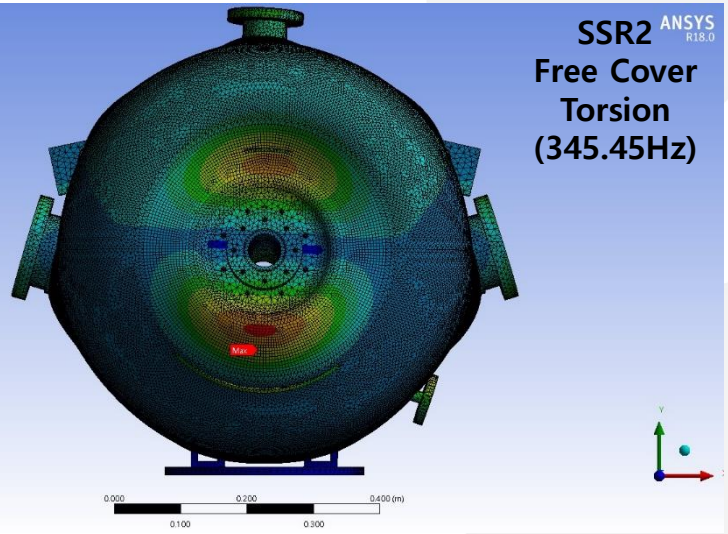
SSR1 Free Cover Fluctuation (240.77Hz)

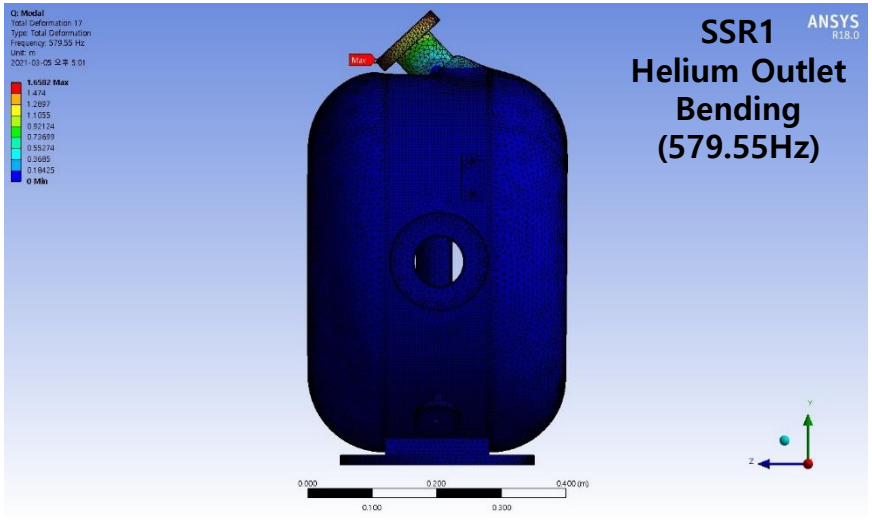


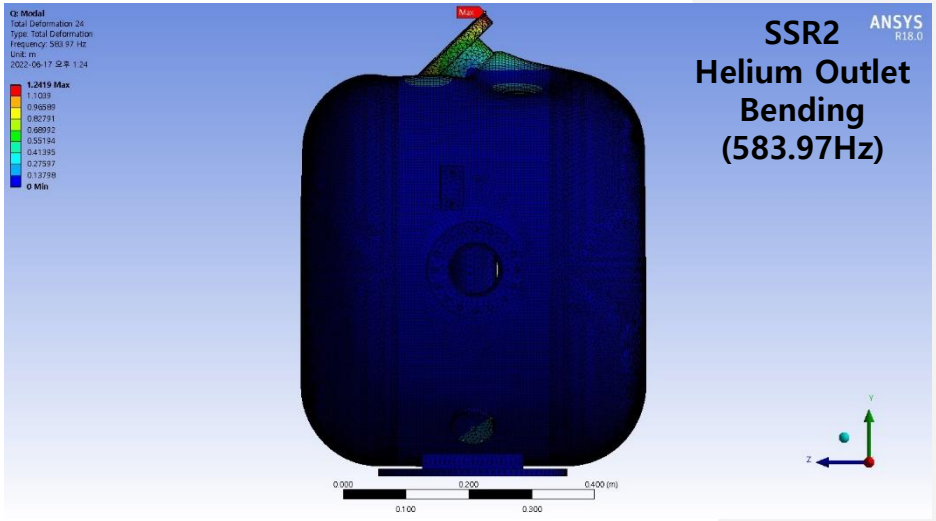
SSR2 Free Cover Fluctuation (218.21Hz)

SSR2 Cavity Design – Modal Analysis

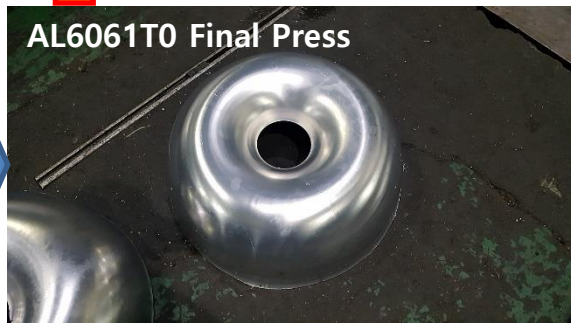






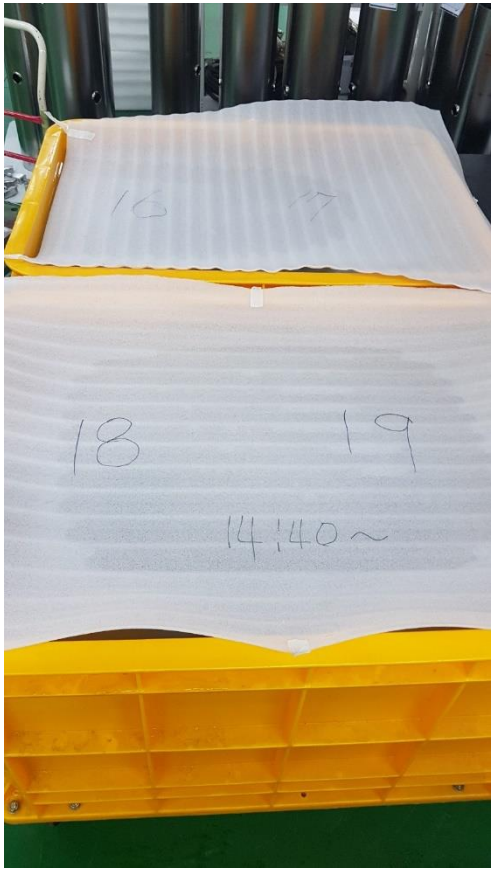


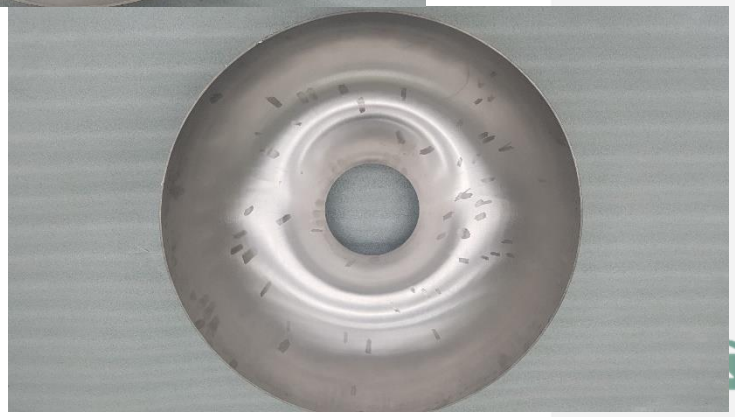
Half Shell Deep Drawing (SSR1)



Salt Water Test (OTIC) (SSR1)

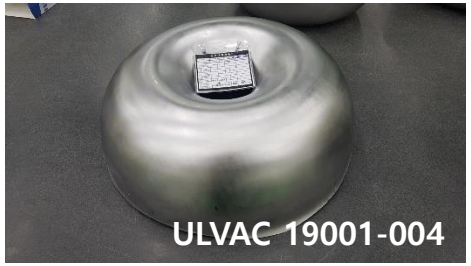
Salt Water Test (OTIC) (SSR1)

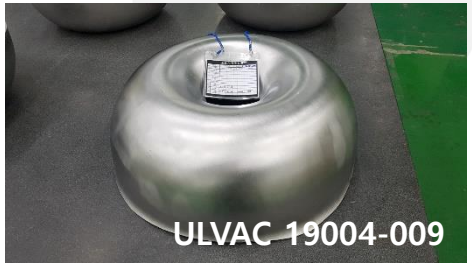


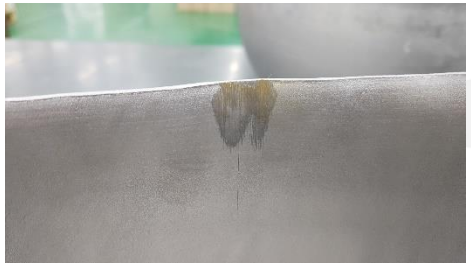


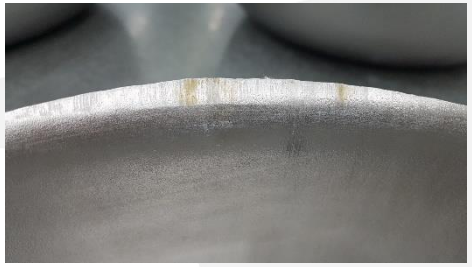
Condition : 10% salt water dipping, drying@class 100
→ rust appeared, removed!

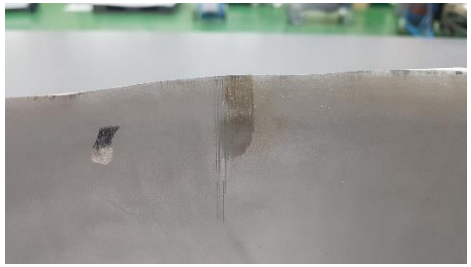
Salt Water Test (UMK) (SSR1)

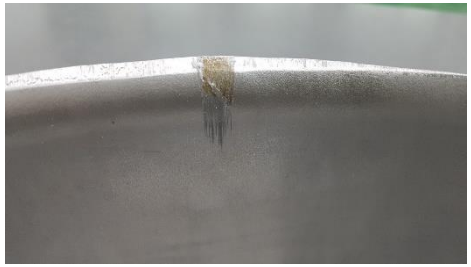


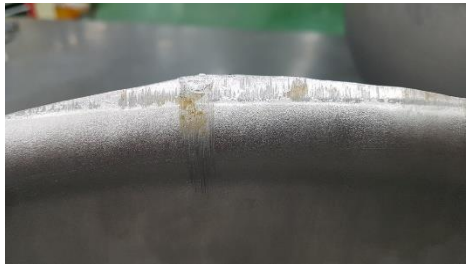


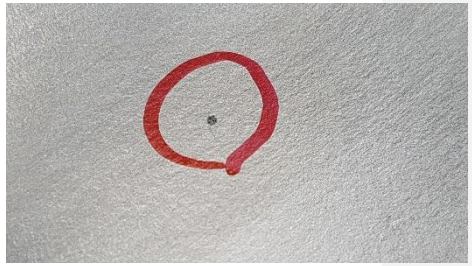




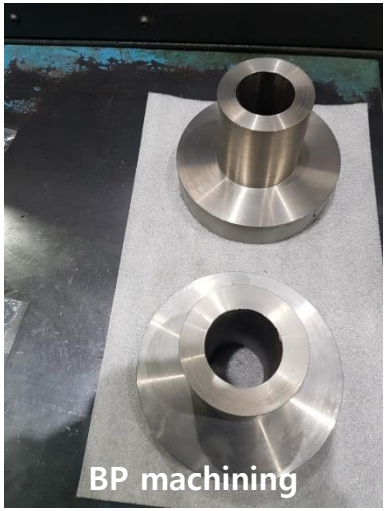








Beam Port (SSR1)


BP machining

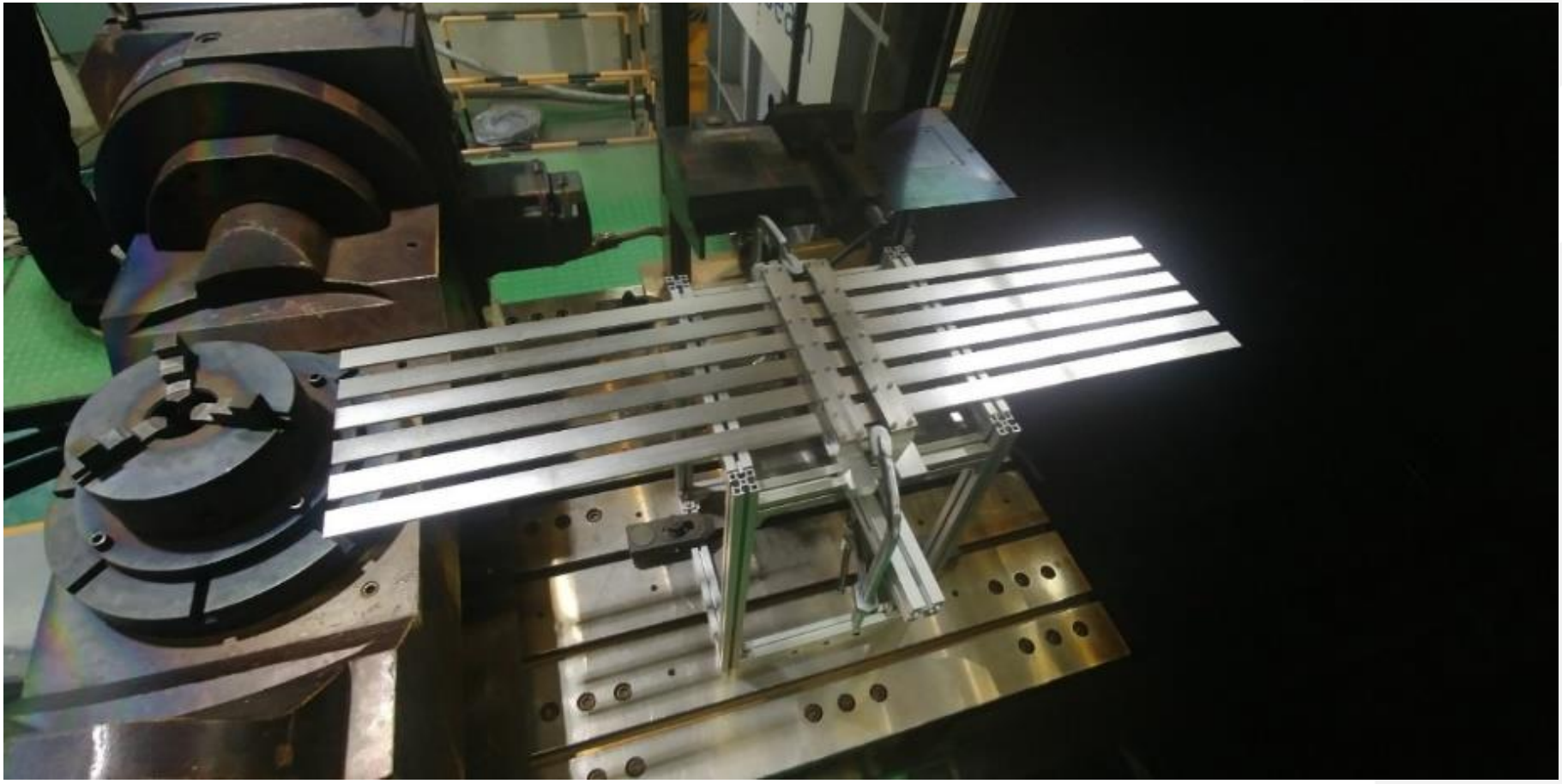

BP/BF inspection


BPA Leak Check


BP/BF Vacuum Braze

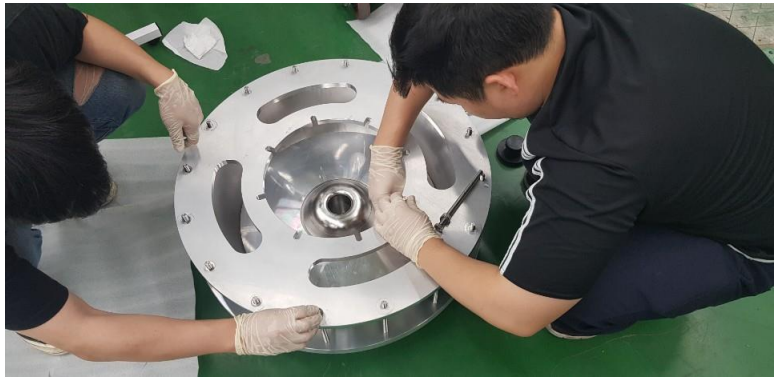

BPA Leak Check

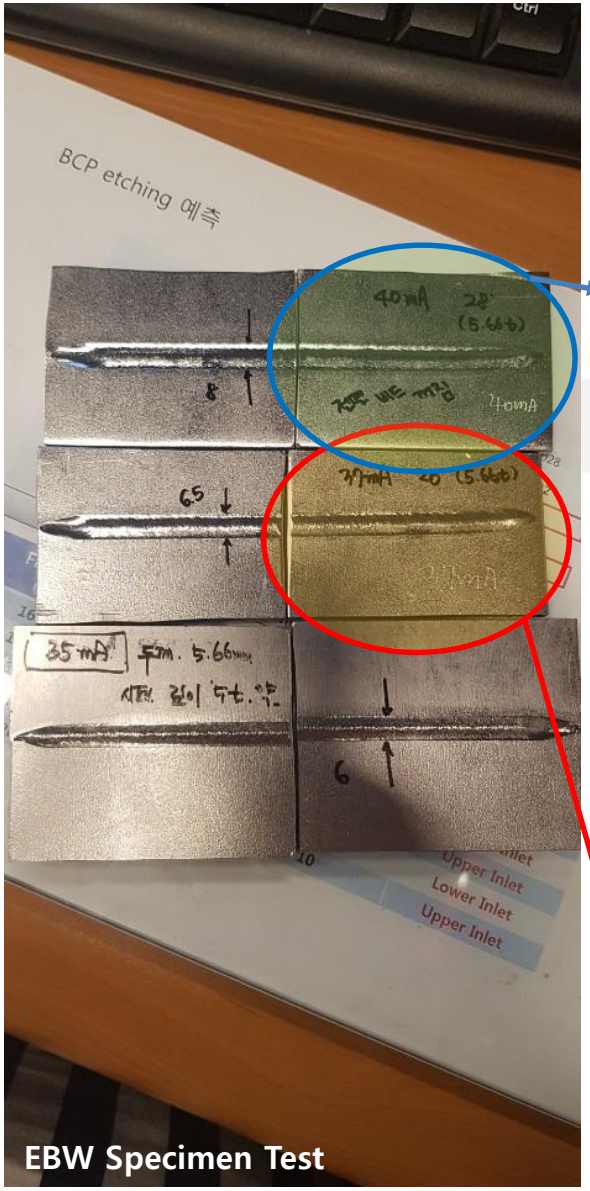
Stiffener Ring (SSR1)



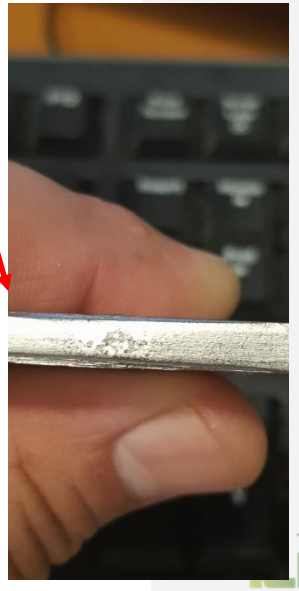
Half Shell EBW Specimen Test (SSR1)

Hume/Gas Trap during BCP

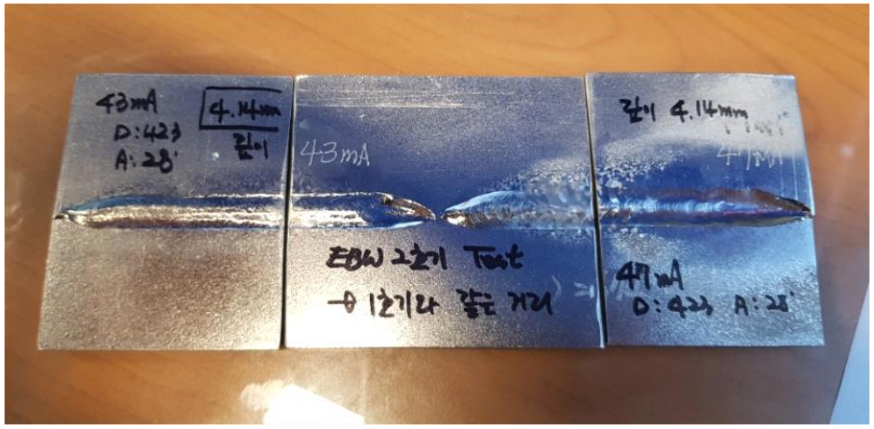


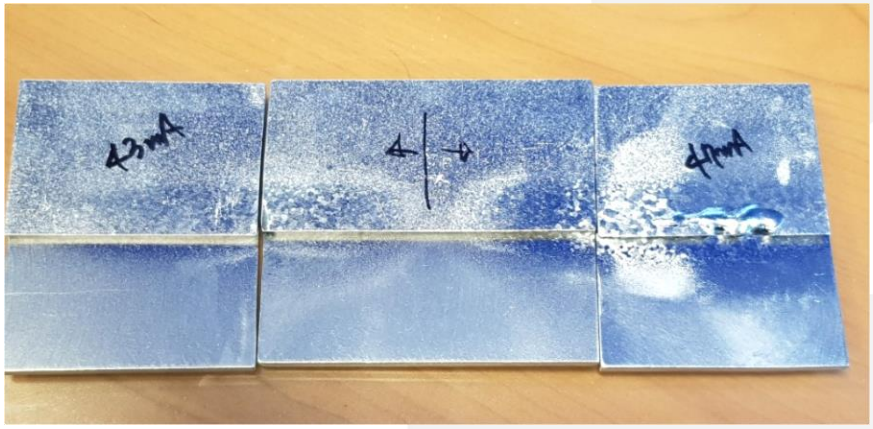


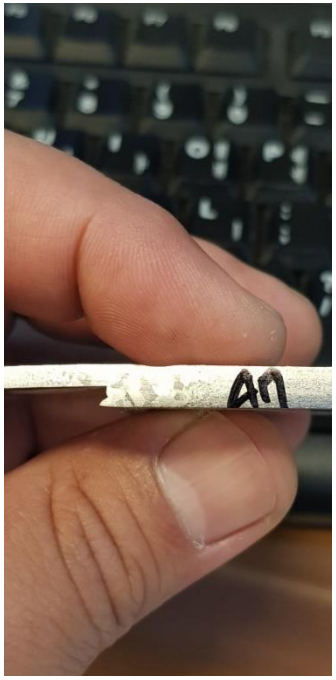
EBW Specimen Test



Half Shell EBW Specimen Test (SSR1)

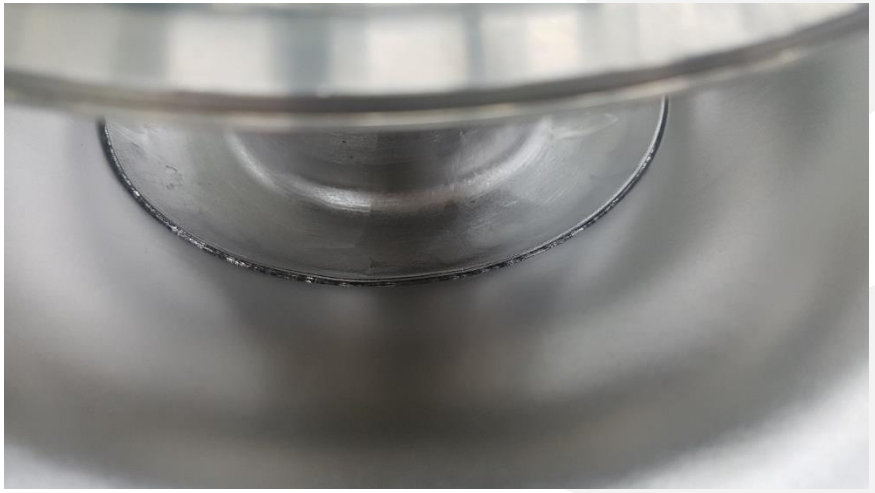






* EBW Specimen Test
 - Initial Conditions : Beam current(BC) 35/37/40mA
 - 1st Test : 35mA (Penetration depth(PD) 50%/Bead width(BW) 6mm), 37mA (PD 60%/BW 6.5mm), 40mA (PD 70%/BW 8mm), all test are not satisfied for full penetration.
 - 2nd Conditions : BC 43m/47mA
 - 2nd Test : 43mA (PD 95%/BW 8.3mm), 47mA (PD 107%/BW 9.2mm), 47mA back bead shape is not uniform.
 - Fixed BC 43mA as final EBW BC condition

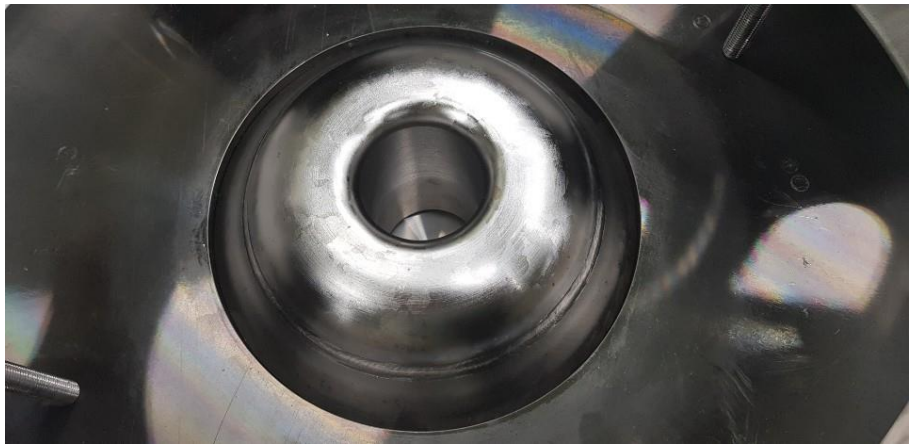
Half Shell + Beam Port EBW (SSR1)



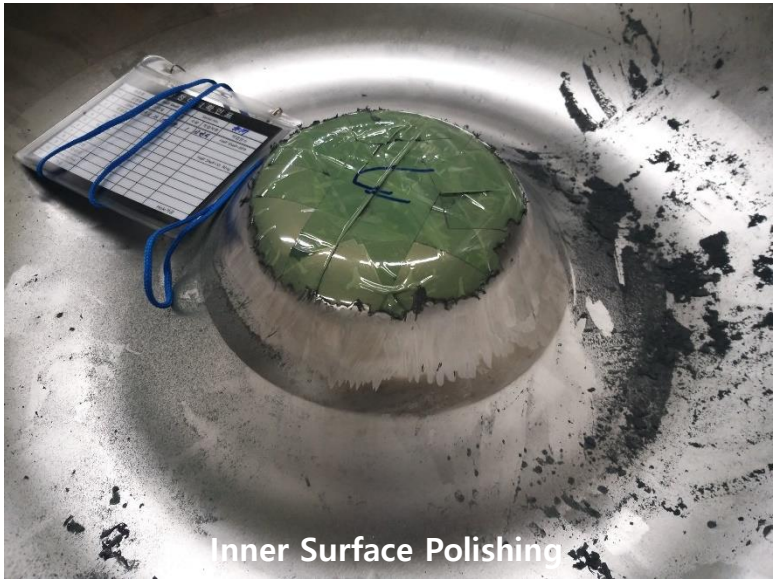
#1 : HS#OTIC16, BP#3, BC 42.1mA

#2 : HS#OTIC17, BP#2, BC 42.1mA

Buffing/Polishing/Cleaning (SSR1)

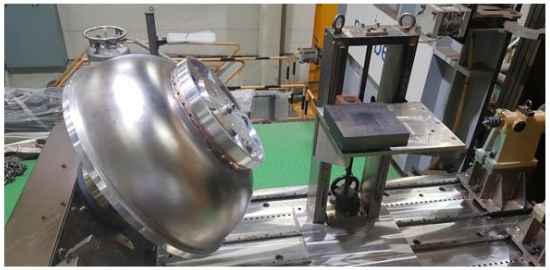


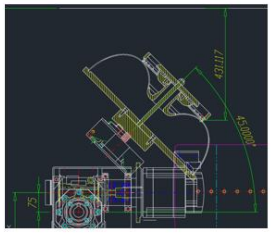
#3 : HS#OTIC18, BP#5, BC 42.1mA

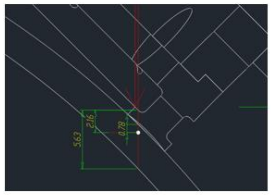


Half Shell + Stiffener Ring EBW (SSR1)

[Half Shell Assembly + Stiffening ring 단선 용접] : EBW 1호기

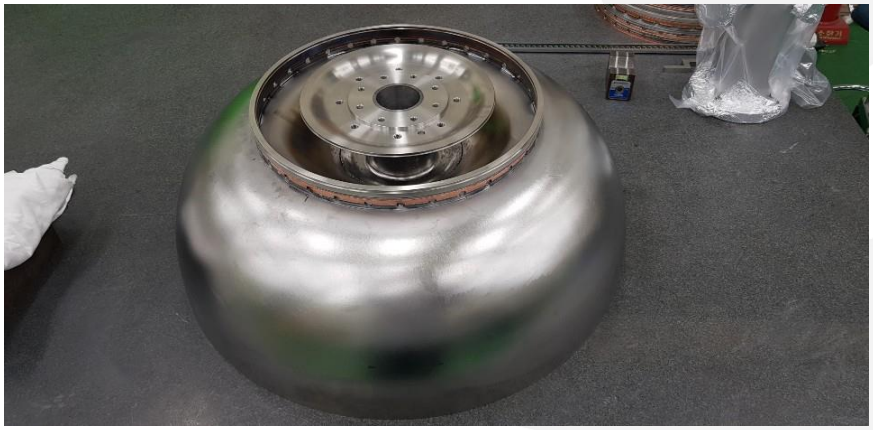




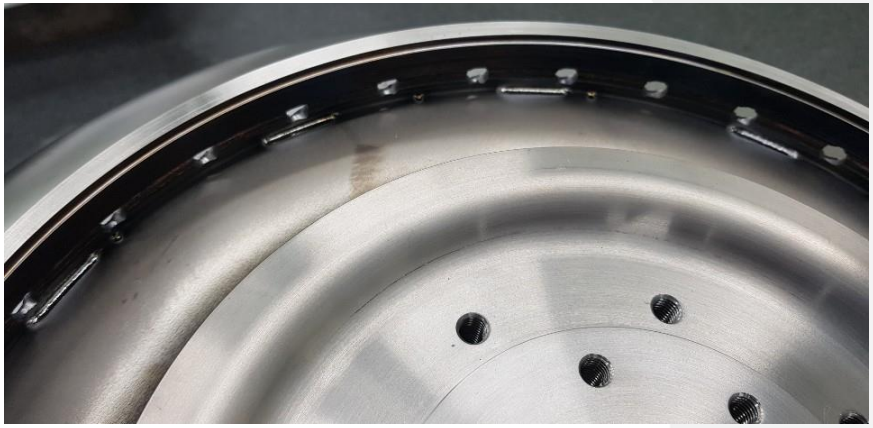


[용접 조건 _ QWR Beam Port Cup Rib 조건 참고]
→ 가접 15mA(Stiffening ring 고정)
1. Focus : -60mA
2. Distance : 438mm
3. Current :17.7mA
4. Beam Size : Ø1.5mm
5. 진공도 : 7.5E-5 torr

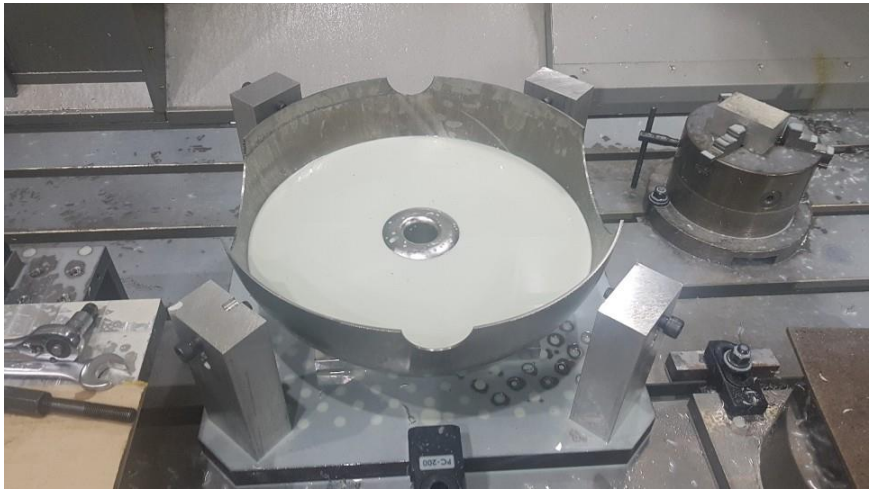
<EBW Setup & Configurations>

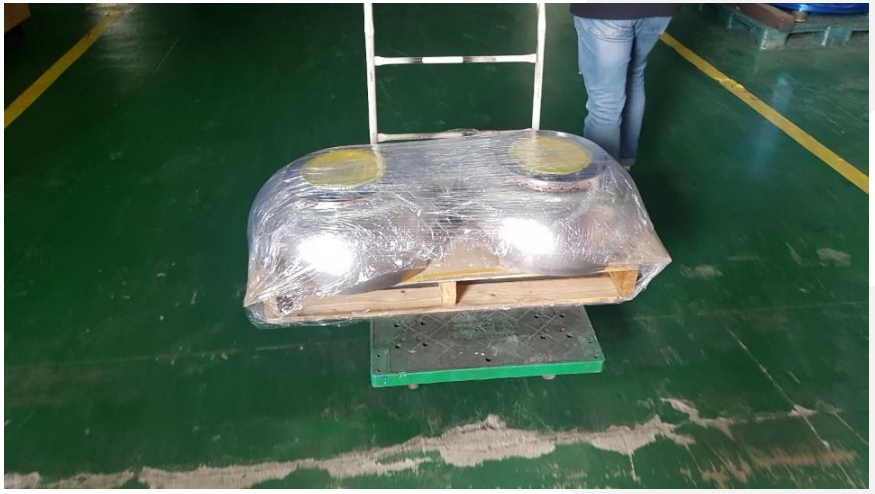


<After EBW of Stiffener Ring>



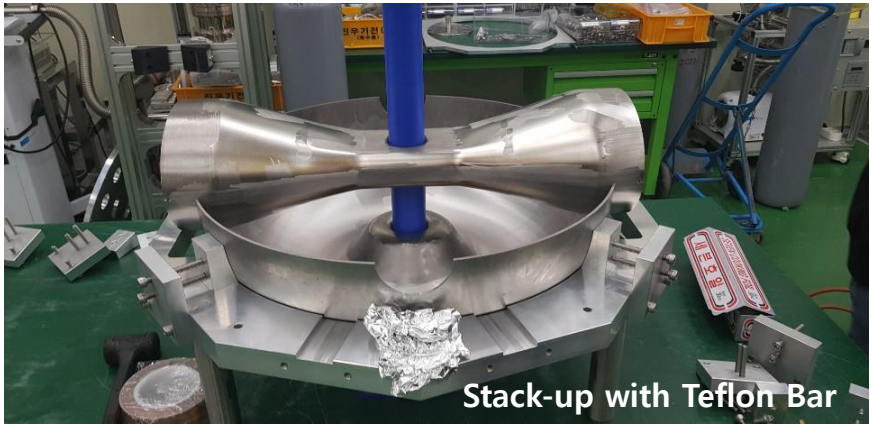
Trimming before Clamp-up Test (SSR1)

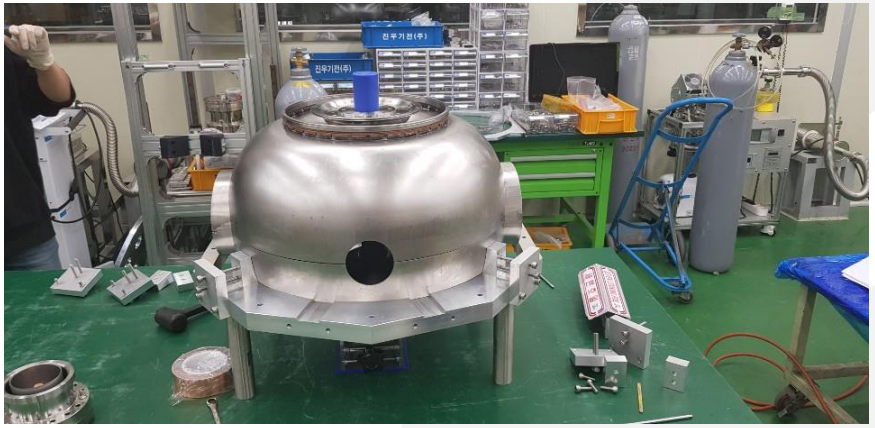




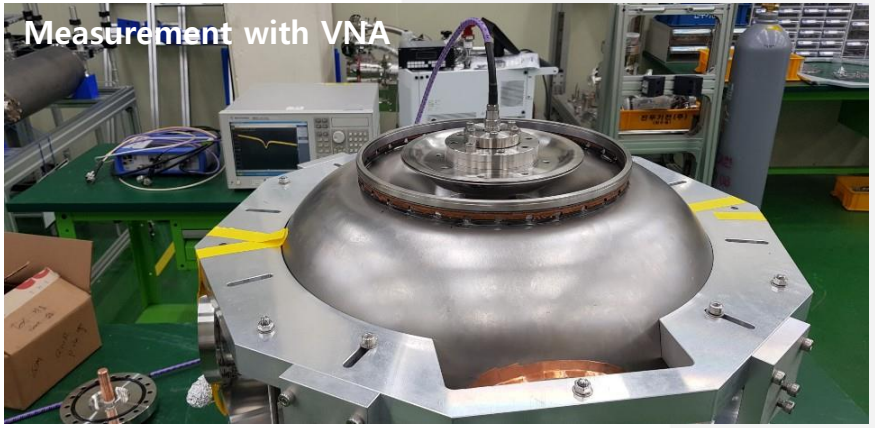
#16/17 Half Shell : Spokes & RF ports Machining for RF Stack-up test
- Lesson & Learn : Machining RF ports after Shell-to-shell EBW due to unexpected misalignment (can make additional alignment during RF stack-up test, EBW and machined-finishing)

Clamp-up Test (SSR1)

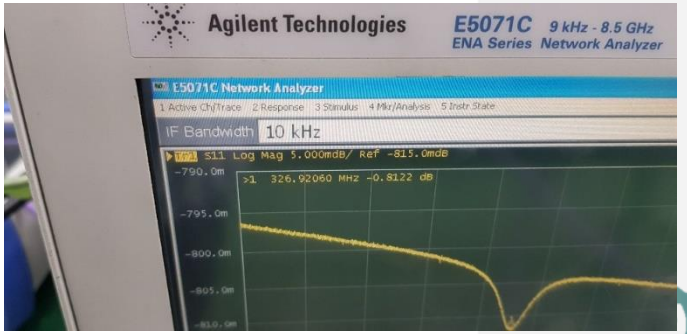

Stack-up with Teflon Bar



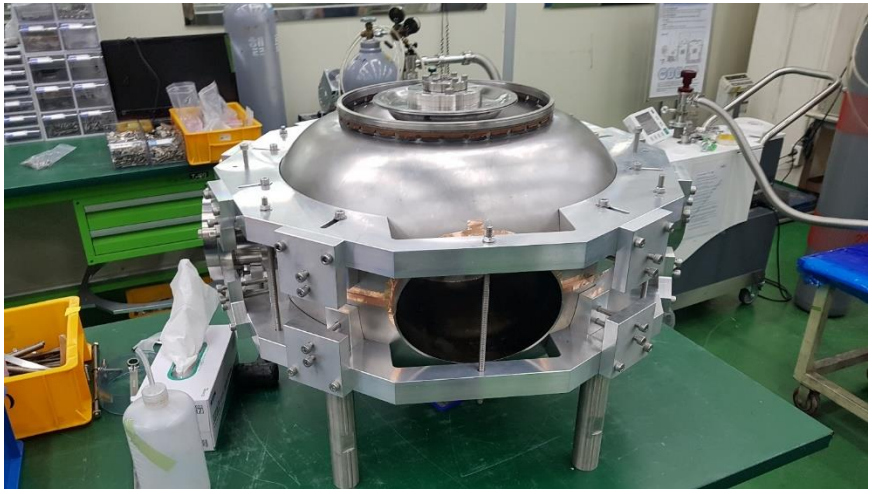

Copper Taping for RF Contact

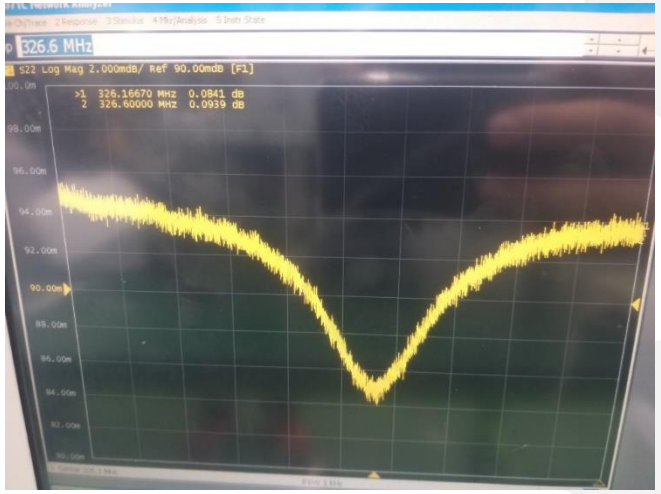

Measurement with VNA

#1 RF Stack-up Test
- **Measured Frequency : 326.92MHz (@Beam Port)**
- **Trimming : 5mm @ each side**

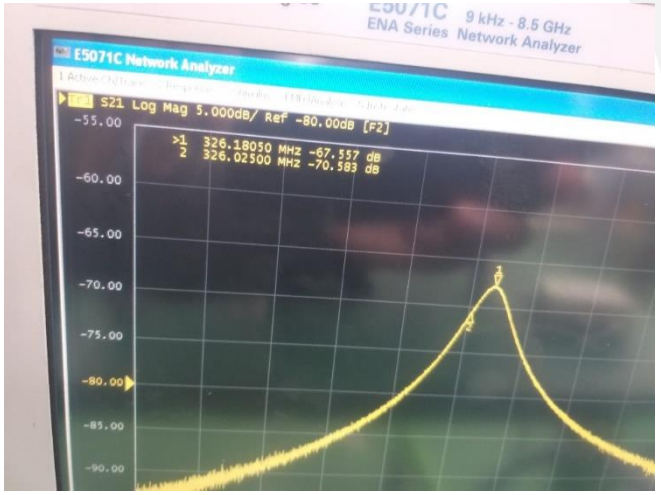


Clamp-up Test (SSR1)

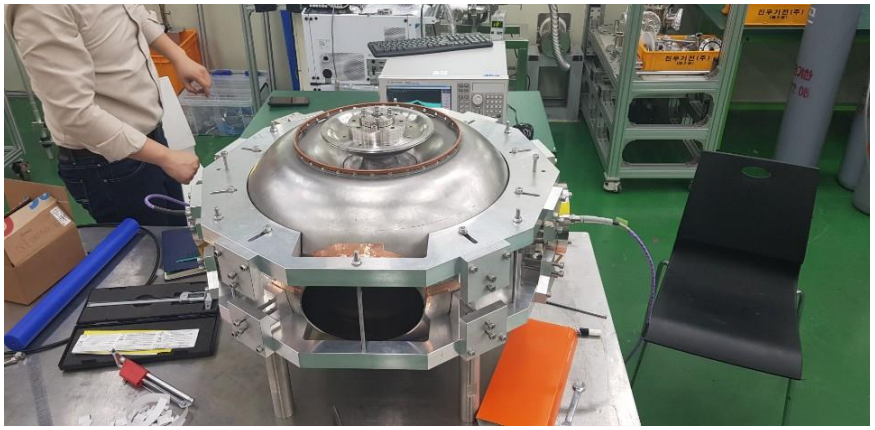


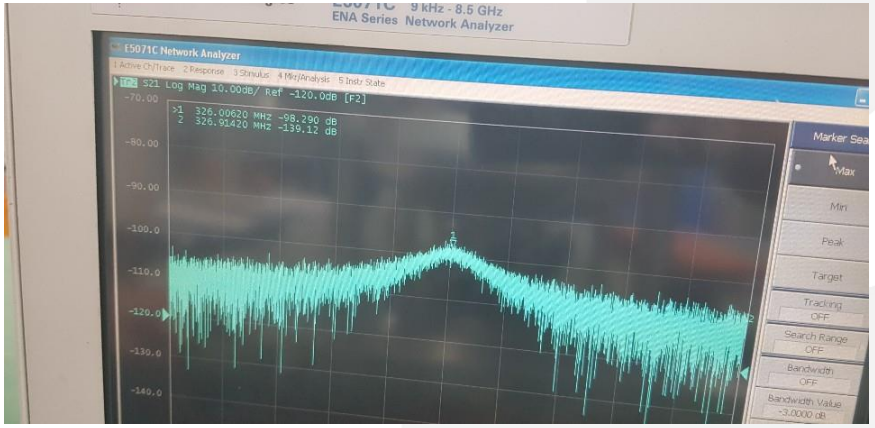


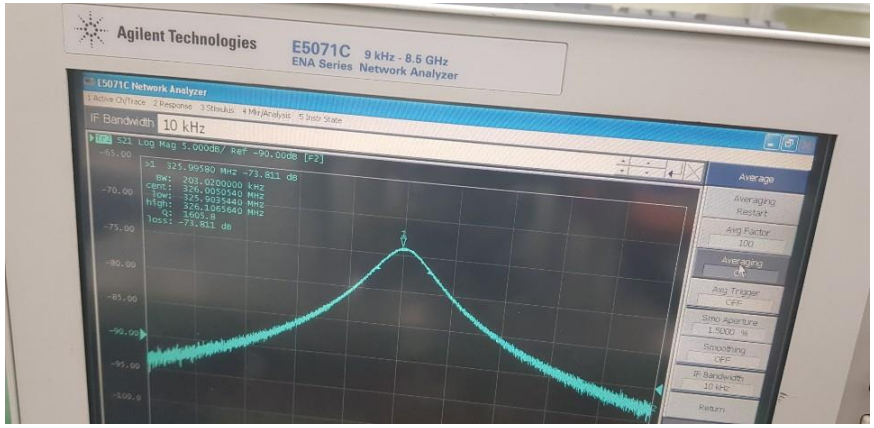
#2 RF Stack-up Test
- Measured Frequency : 326.18MHz
- Trimming : 3mm @ each side
- Frequency Change Estimation
  .. 5mm Trimmed : -740kHz (-74kHz/mm)
  .. 3mm Trimmed : -444kHz (estimated)



Clamp-up Test (SSR1)

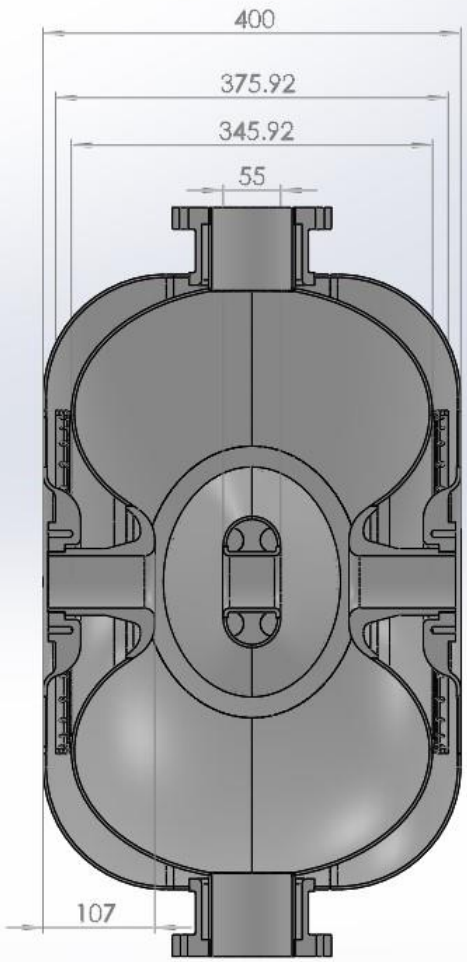






#3 RF Stack-up Test
- **Frequency : 325.99MHz**
- **Freq. Change : -190kHz (estimated -444kHz)**
- **Ratio : 31.67kHz/mm (5mm trimmed : 74kHz/mm)**

Final Trimming Length Decision (SSR1)

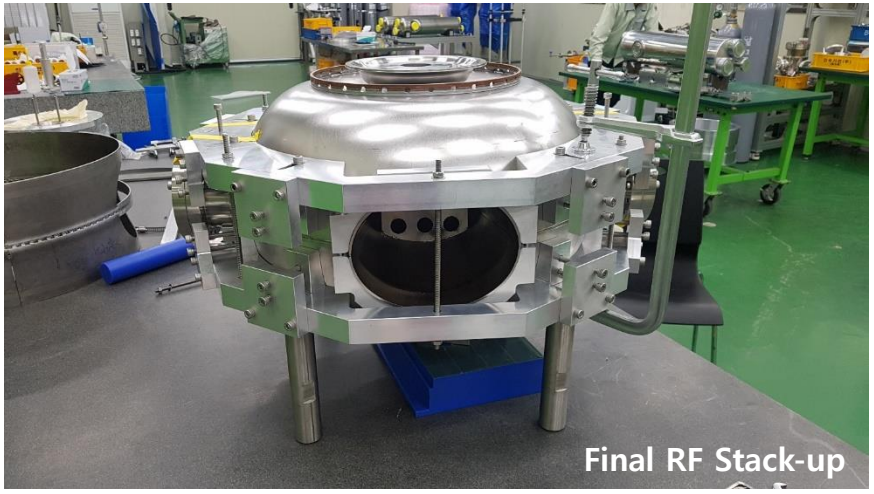


- Dimension Check
  .. #16
    * Flange to Beam Cup : 107.95mm (+0.95)
    * Stiffener to Shell Edge : 202.17mm (**+2.17**)
    * Beam Cup to Shell Edge : 96.69mm (**+1.69**)
    * Flange to Shell Edge : 204.64mm (+4.64)

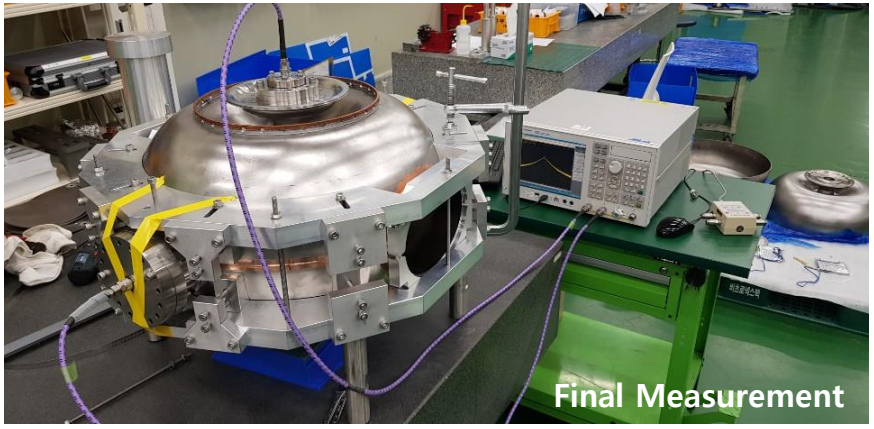
  .. #17
    * Flange to Beam Cup : 107.07mm (+0.07)
    * Stiffener to Shell Edge : 190.4mm (**+2.04**)
    * Beam Cup to Shell Edge : 96.34mm (**+1.34**)
    * Flange to Shell Edge : 203.41mm (+3.41)

  .. Final trimming : #16 1.69mm, #17 1.34mm

Clamp-up Test (SSR1)


Final RF Stack-up

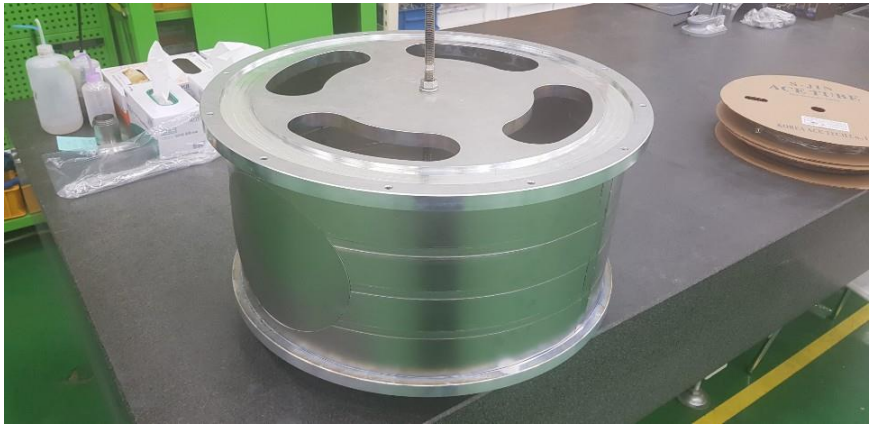

Precisely-Machined
Welding Line

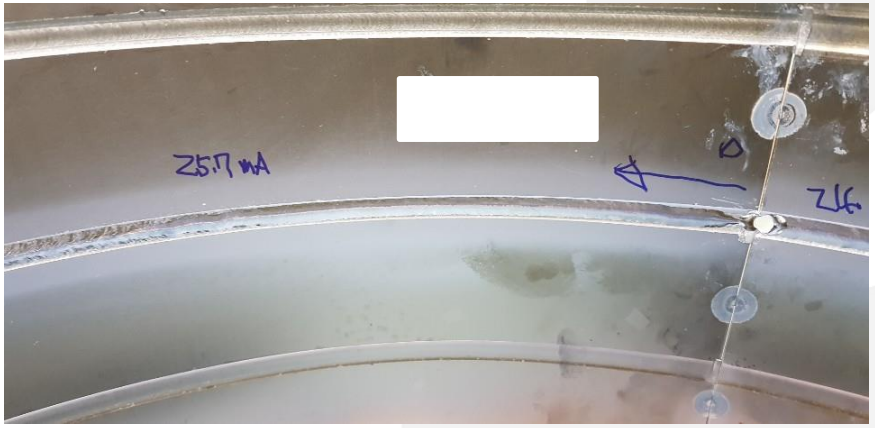

Final Measurement

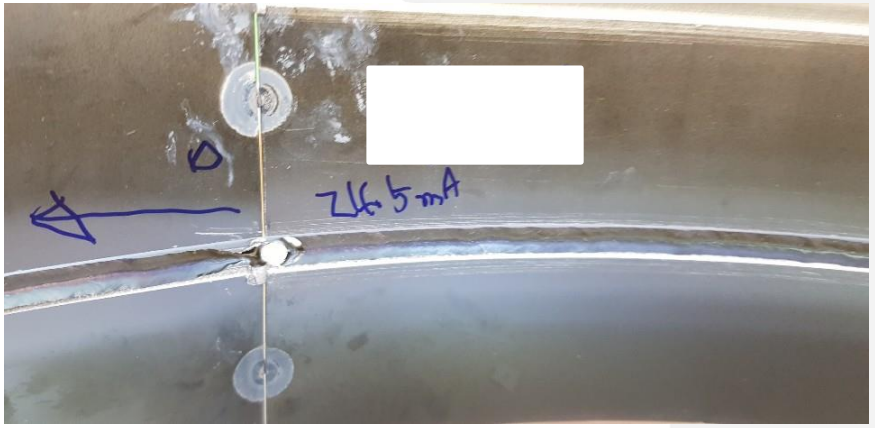
#4 (Final) RF Stack-up Test

- **Frequency : 325.284MHz (233kHz/mm) → Fixed for considering EBW shrinkage**
- **Shell-to-shell EBW preparation : BCP/Rinsing/Drying, EBW Setting, etc.**

Shell-to-Shell EBW Test (SSR1)

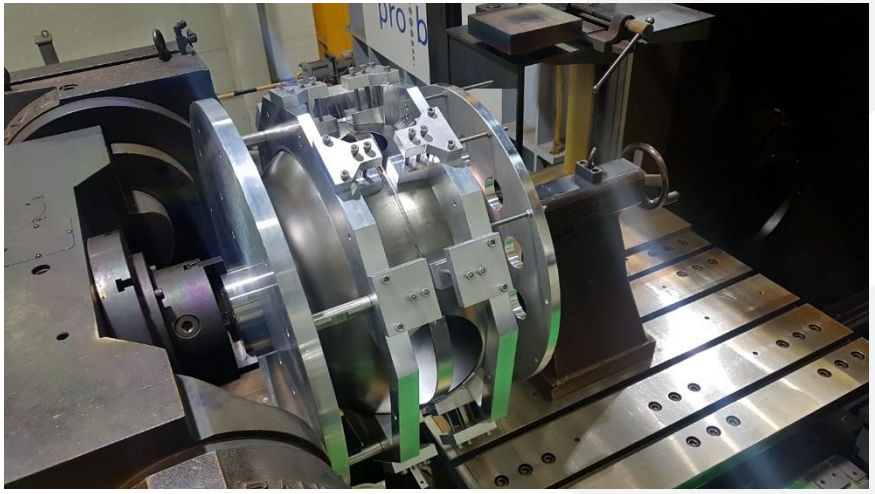


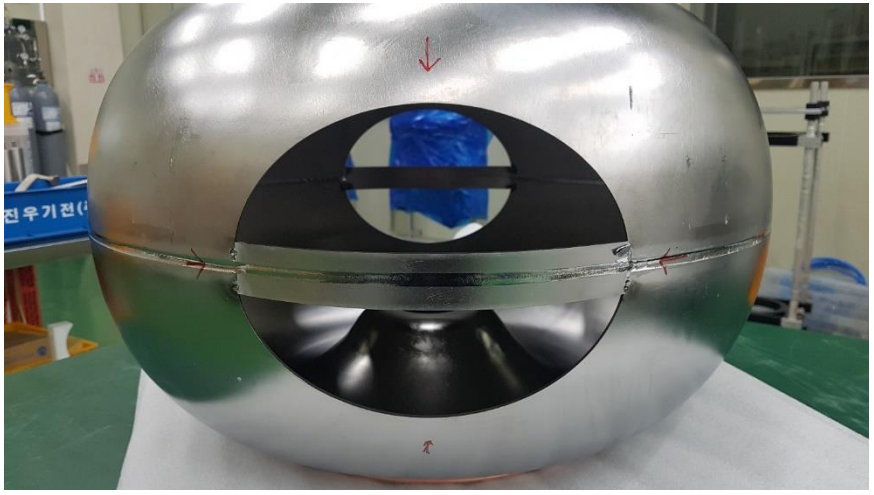


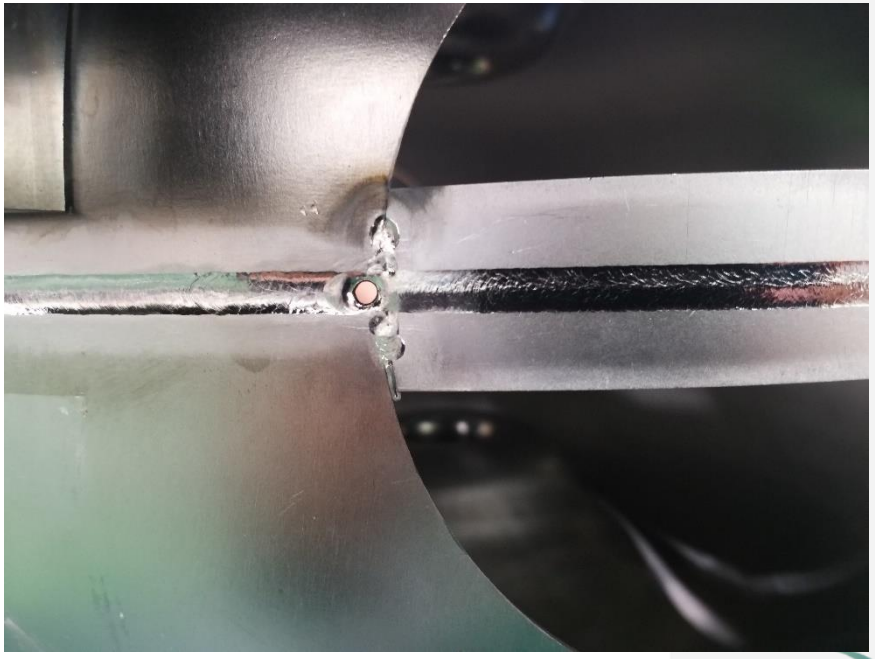


2nd test for S-T-S EBW
- **Conditions : BC 25.7~24.5mA**
- **Over-melted @ 2 points → Reduce beam current!**

Shell-to-Shell EBW (SSR1)



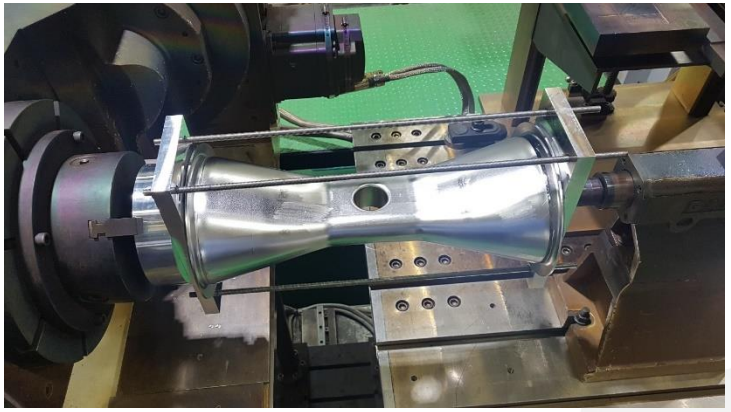




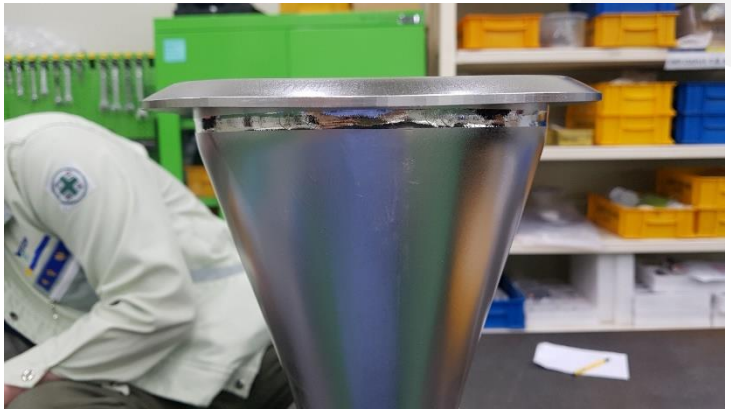
S-T-S EBW : OK
- Hole around tacking → Removing Area!

Spoke-to-Collar EBW (SSR1)









S-T-C EBW : OK
- Trimming, Measurement
- Upper EBW, Lower EBW
- BCs are varied corresponding to the curvature.
- Issues : tailstock is loosen during upper EBW → Fixed!
- Fully penetration is OK! → Buffing & Surface Finishing

Shell-to-RF ports EBW (SSR1)


RF Ports Standby


Thermal Shock Test

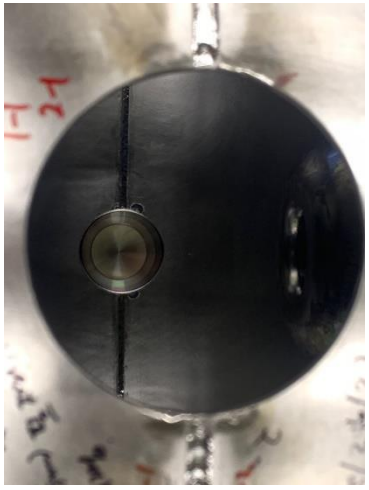
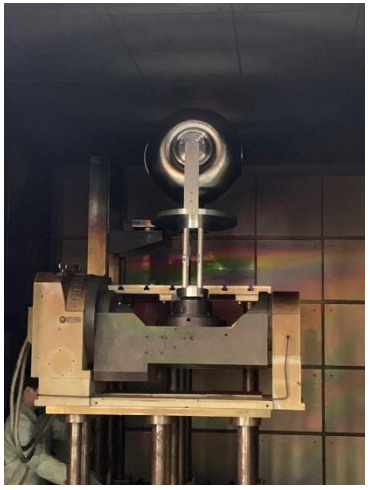
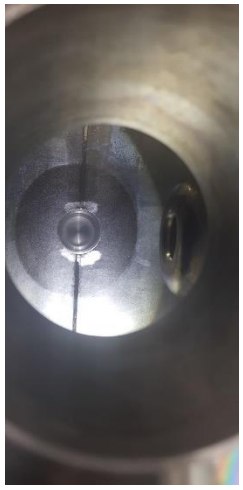

Weldment Specimen

Shell-to-RF Port EBW
- **EBW Specimen, RF Ports thermal shock test, Fixture Setup**

Shell-to-RF ports EBW (SSR1)

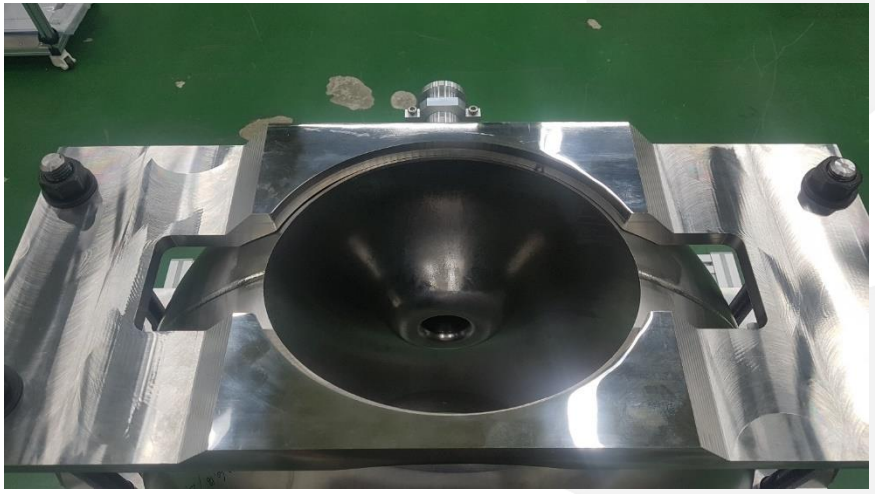


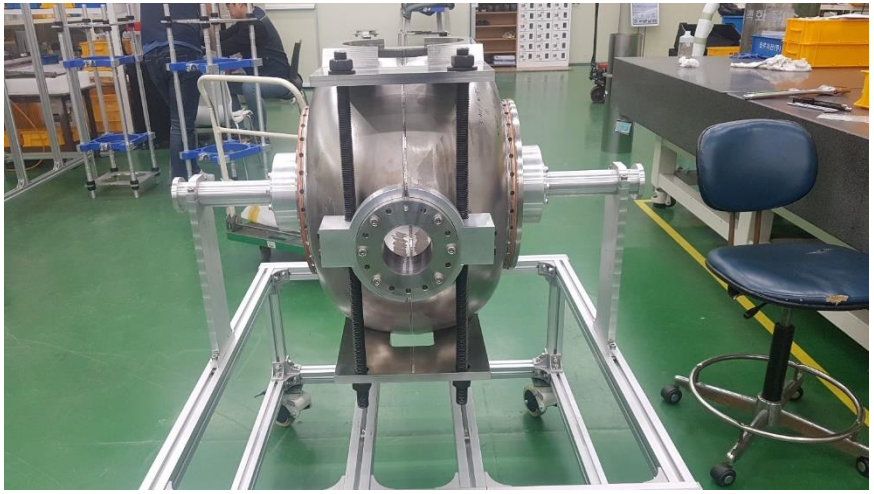


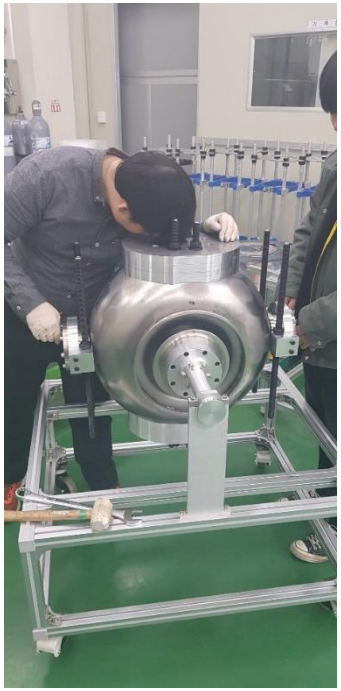





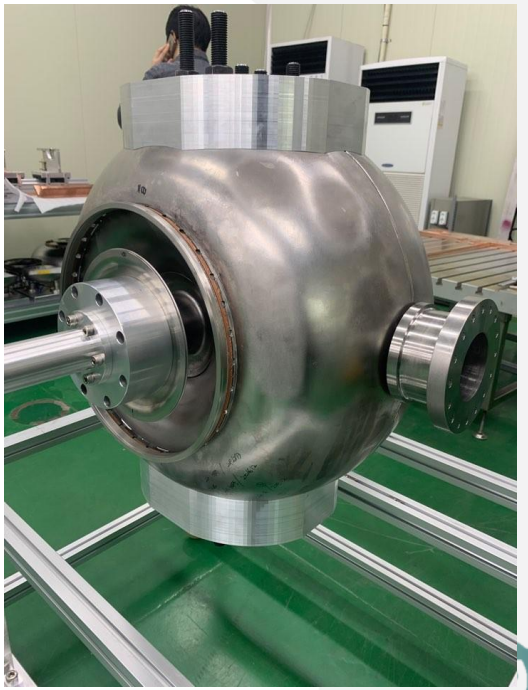
Shell-to-RF Port EBW
- **Left-side port EBW, Right-side port EBW**

Shell Adjustment (SSR1)



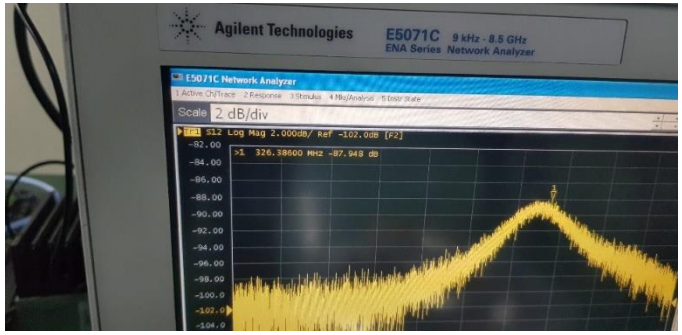


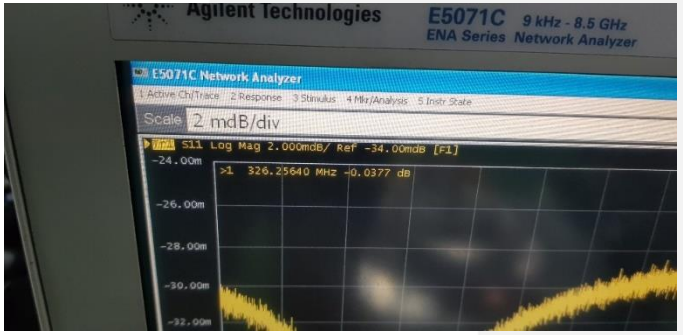




Fixture Design & Making
- **Not adjusted!, modified fixture**

Shell Adjustment (SSR1)

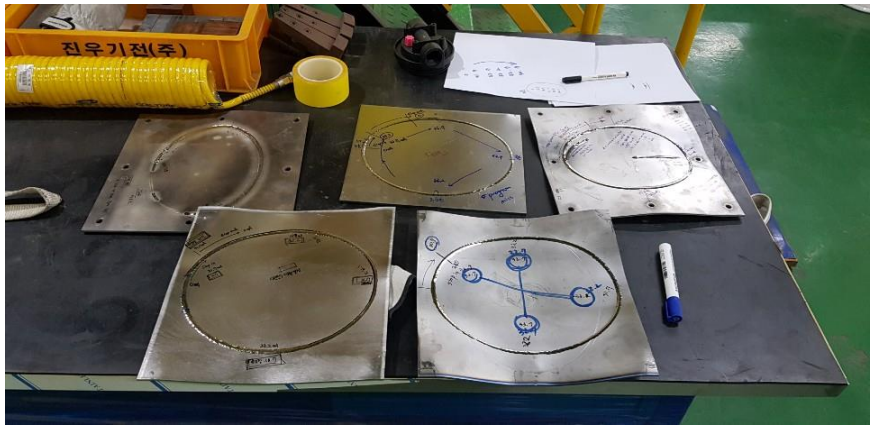


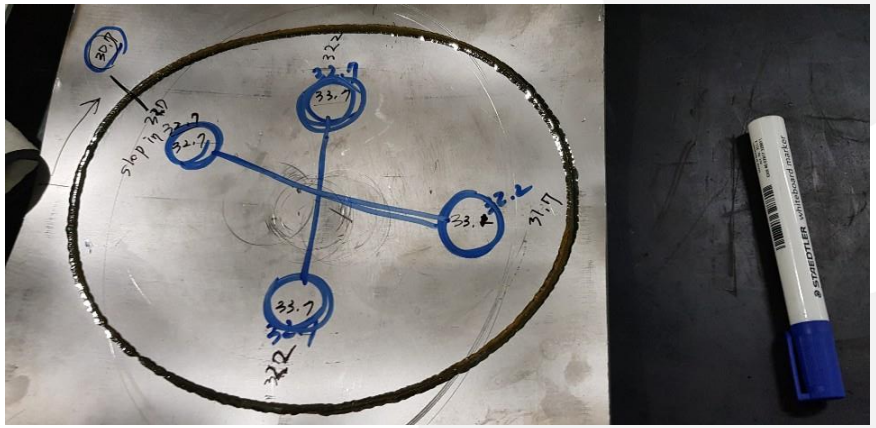


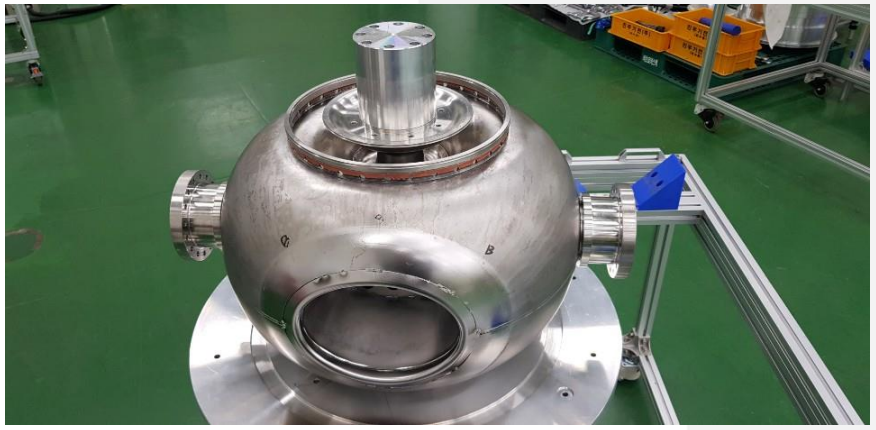
Modified Fixture Adjustment

- 1mm Gap : fixed! → RF Stack-up test → 326.25MHz frequency (Increased!)
- Beam Cup-to-cup measurement : 191.2mm (+1mm)
- Calculation : 460kHz/mm (BC sensitivity) + 200kHz (Collar difference) +@
- Possibility of detuning after Final EBW/BCP/HPR/HTB/LightBCP/HPR!
- Go to the Final EBW

Shell-to-Spoke EBW Test (SSR1)



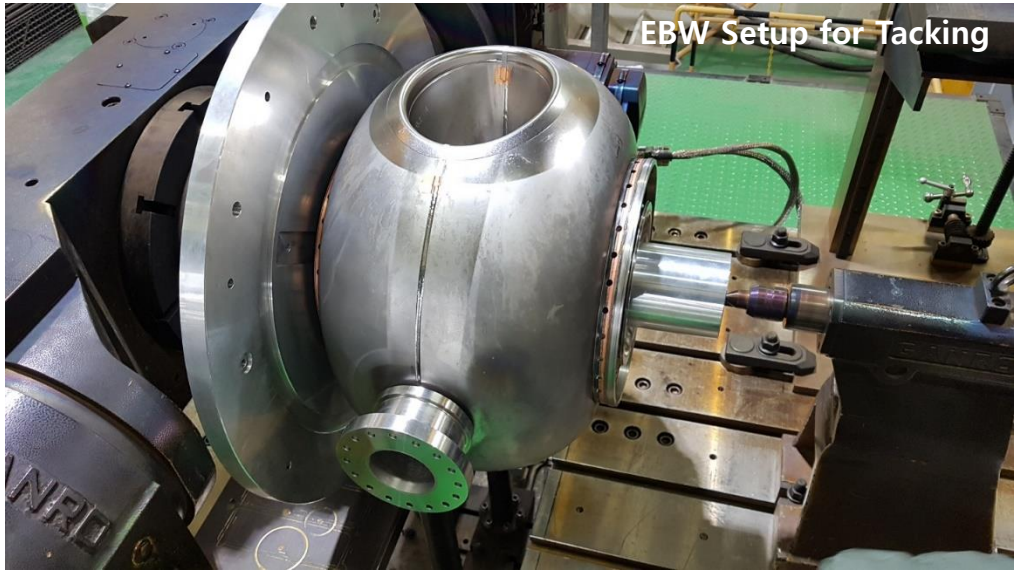




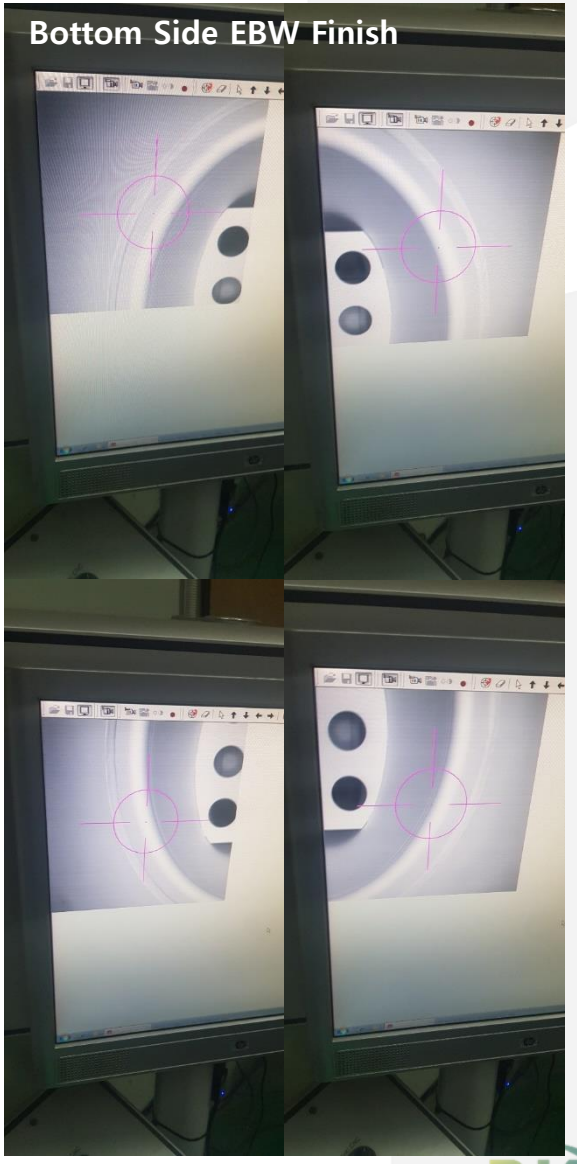
Shell-to-Spoke EBW

- **Specimen Test : EBW Condition : 32.7→ 33.7 → 33.2 → 33.7 → 32.7mA**
- **Spoke Tacking : Point/Short-line EBW for posture fixing**

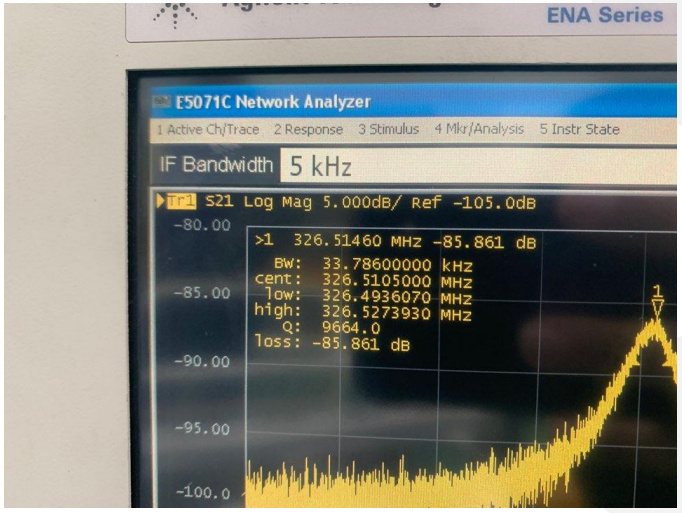
Shell-to-Spoke EBW (SSR1)



Shell-to-Spoke EBW (SSR1)



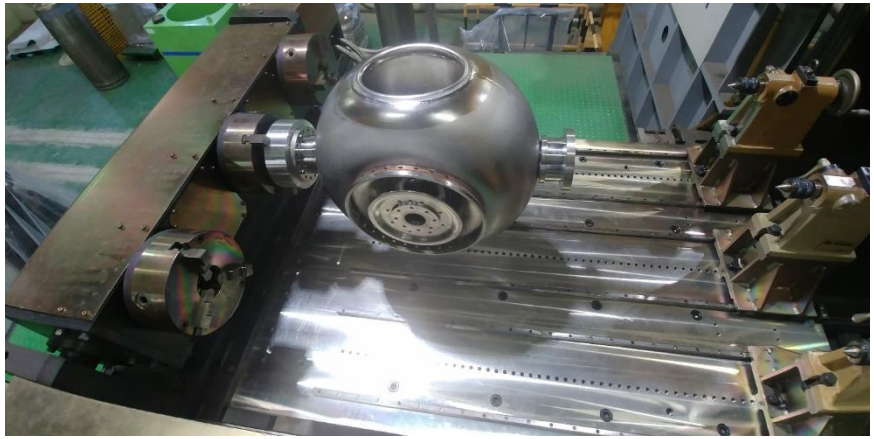
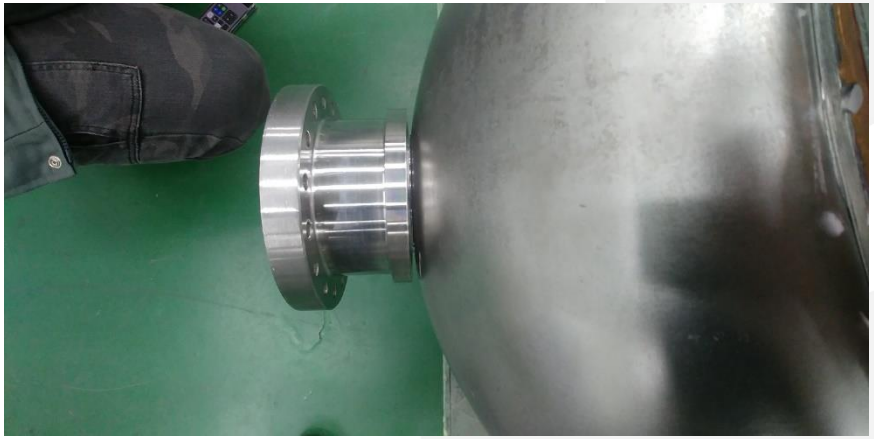
Frequency Check (SSR1)

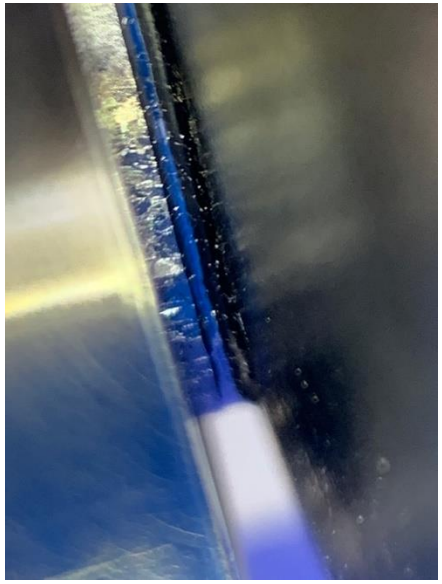
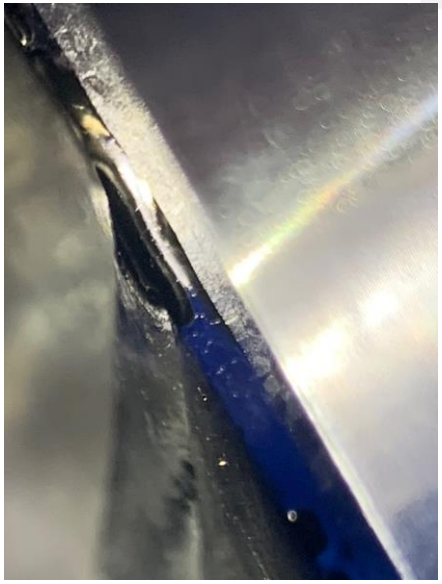
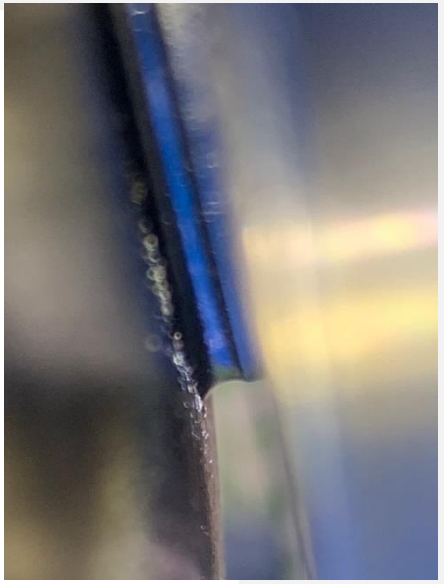


	#1 공정	Frequency	비 고
1	[Clamp Up TEST] 211mm/199mm	326.9206 MHz	3차원 측정 후, 상하 비대칭 발견
2	[Clamp Up TEST] -5mm/-5mm	326.1667 MHz	Half Shell + Half Shell 용접 단 가공
3	[Clamp Up TEST] -3mm/-3mm	325.8230 MHz	
4	[Clamp Up TEST] -1.17mm/-0.82mm 200mm/188mm	325.2841 MHz	내부 형상 맞춤 / 용접 수축율 0.8mm Beam Port Cup to Beam Port Cup 190mm (95mm)
5		326.3680 MHz	Half Shell + Half Shell 용접 후 SPOKE HOLE 가공
6	Final Welding	326.5146 MHz	

- **Frequency Change : 325.2841MHz → 326.5146MHz (+1.2305MHz increase!)**
- **Root Cause : BC Gap increase (460kHz) + Collar Change (200kHz) + MC/EBW Distortion (570kHz)**

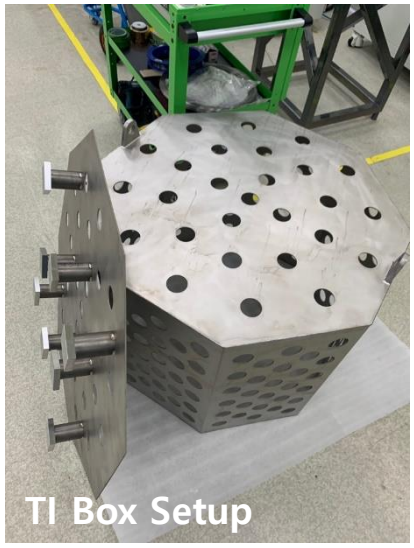
RF Port EBW Repair (SSR1)

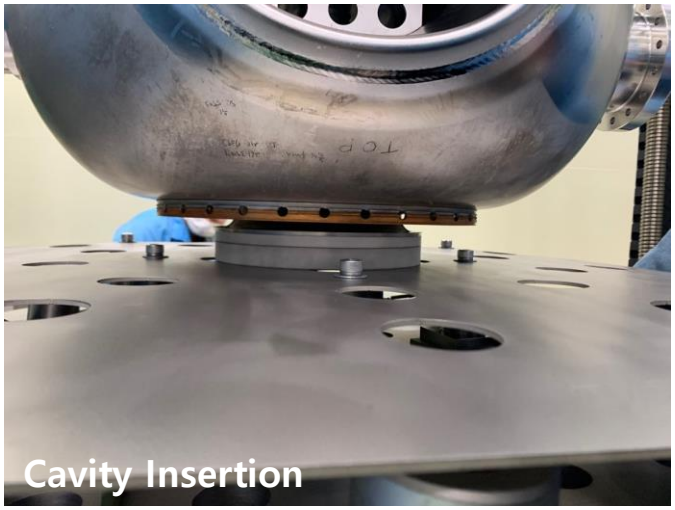



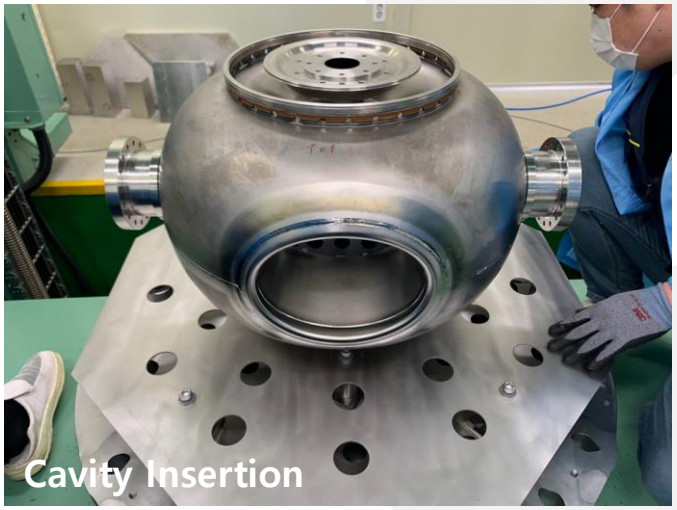




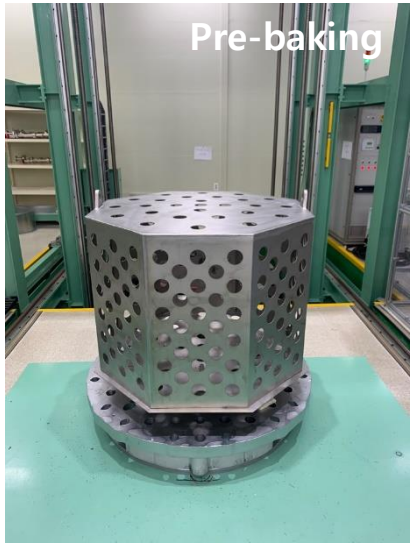
- RF Port Leak : Re-EBW → Leak is not disappeared… → What's next?

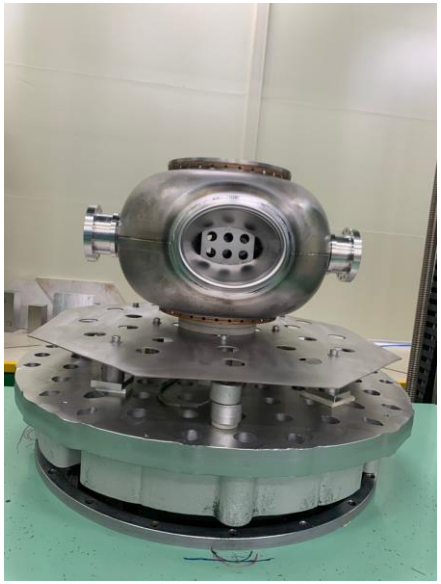
High Temperature Baking (SSR1)

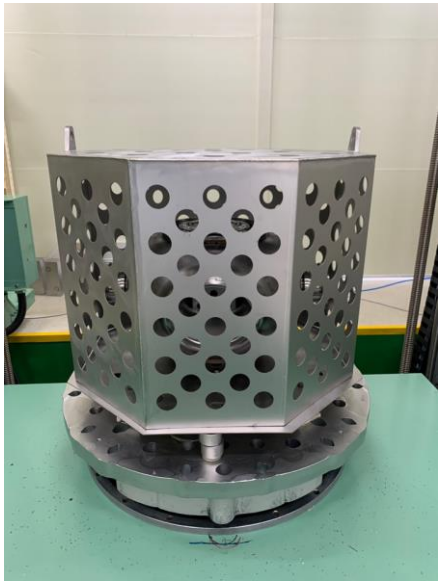

TI Box Setup

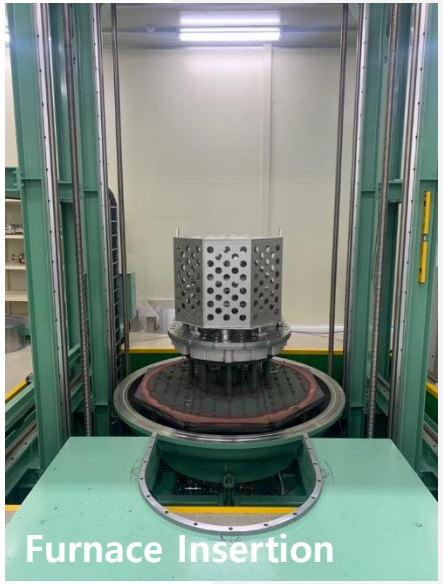

Cavity Insertion


Cavity Insertion

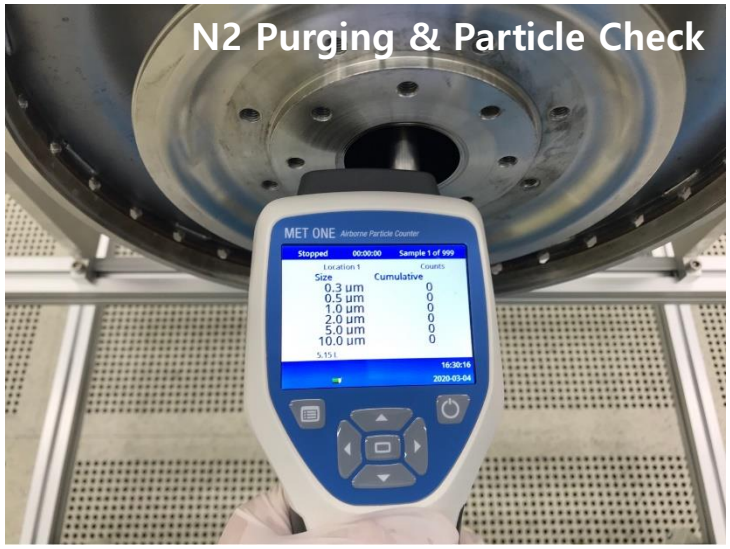

Pre-baking

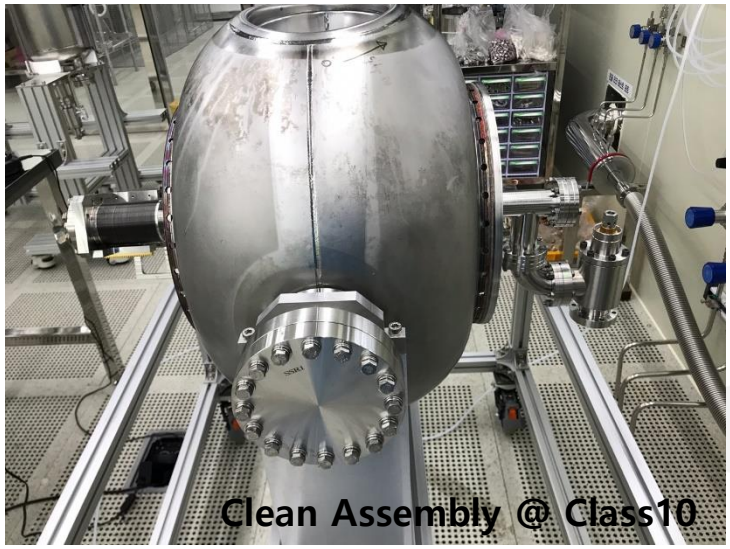




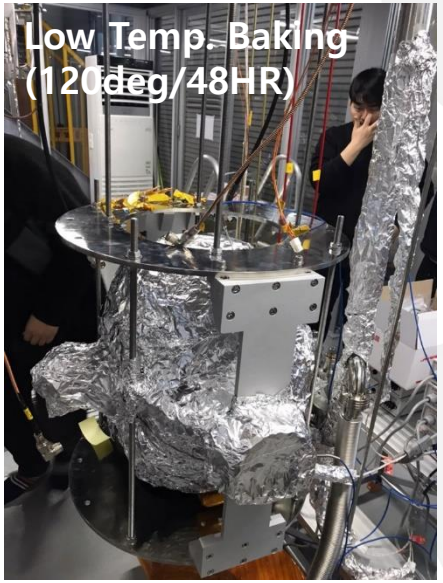

Furnace Insertion

Cleanroom Assembly (SSR1)





Cold Test Preparation (Munji) (SSR1)



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3. MP Simulation Results of TRIUMF SSR1 Collar Round (HC Jung, 2018)
4. RISP SSR2 Pre-Fabrication Design Report (RISP AST, 2018)
5. Technical Advisory Committee Final Report (IBS, Daejeon, 2018)
6. Balloon-Variant of Single Spoke Resonator (Z.Yao et al, SRF2015, THPB021)
7. Mechanical Design of Single Spoke Resonator Type-2 SC Cavity for RISP (MO Hyun et al, HIAT2018, WEOYA01)
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9. Modal Analysis and Vibration Test of Single Spoke Resonator Type-1 (SSR1) for RAON (MO Hyun et al, SRF2021, THPCAV001)
10. Mode Analysis of Single Spoke Resonator Type-2 (SSR2) for RISP (MO Hyun et al, HIAT2022, FR1C3)