PIP II Technical Meeting- # WG1

Status of 650MHz Cryomodule Development at RRCAT

Authors: Rupul Ghosh,
CDCAS
Proton Accelerator Group,
Raja Ramanna Centre for Advanced Technology, Department of Atomic Energy, India

PIP-II Technical Meeting @ Fermilab USA
working Group 1 HB650 Cryomodule Production
July 12-14, 2022

Outline

- Phase-1 Deliverables in R&D Phase
- Design of Thermal shield
- Horizontal Test Cryostat Design and Fabrication
- Phase-2 Preparation for Cryomodule Components Fabrication and Assembly
- CM Coldmass Assembly Infrastructure Development
- Initiation of Vendor Development
- Summary

Phase-1: Deliverables in R&D Phase

Deliverables Related to Cryomodule in R&D Phase

Table 9: Section 6.8. Superconducting Cryomodule Design

(As per Addendum-1 of Joint Project document for R&D Phase of IIFC Collaboration)

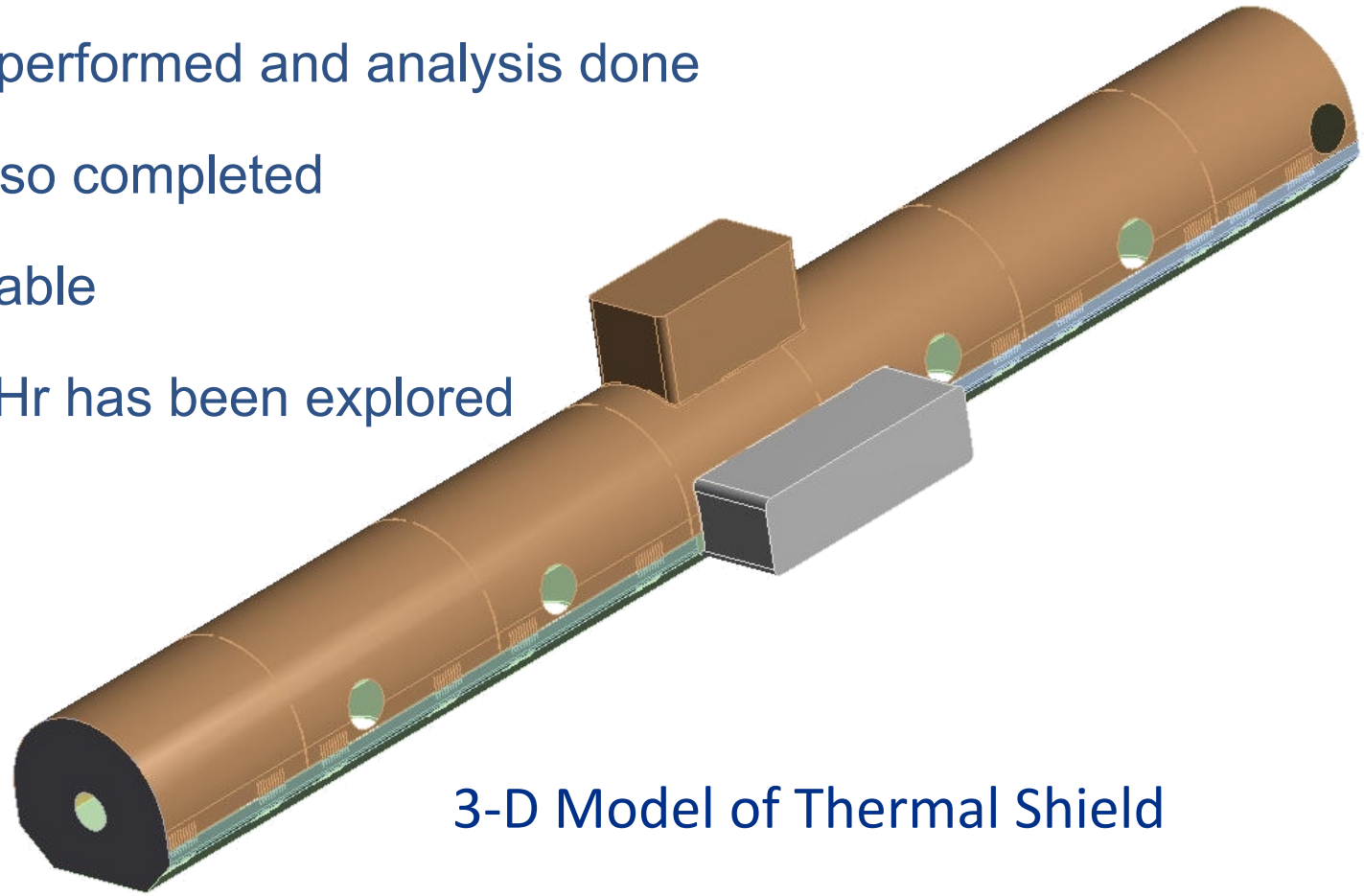
Milestone	Major Milestone	Quantity	Responsibility	Delivery Date	New Delivery Dates	Remarks
1	Technical requirement specification (TRS)(325 MHz & 650 MHz)		FNAL	31 Oct 2015	Aug 2019 (325 MHz) Aug 2019 (650 MHz)	
2	Design of 325 MHz SSR1 Cryomodule		FNAL	Done	Dec 2019	
3	Design of 325 MHz SSR2 Cryomodule by DAE laboratories and Fermilab		DAE	31 Jan 2018	Sep 2022	
4	Design of 650 MHz LB/HB Cryomodule DAE laboratories and Fermilab(Thermal Shield)[$1]		DAE+FNAL	28 Feb 2017	Nov 2020	#1

[$1]Change of scope. Only thermal shield design is now required.

Design of 70K Thermal Shield

Following Calculation/Analysis has been done for thermal shield

- Calculated the mass flow rate required and h value
- Analytical calculation for finger welds performed and analysis done
- Transient thermal analysis of shield also completed
- Cooldown rate of ~8-10K/Hr is achievable
- Possibility of faster cool down of 20K/Hr has been explored

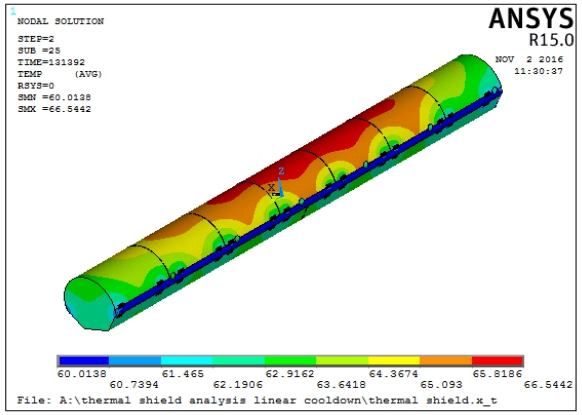


3-D Model of Thermal Shield

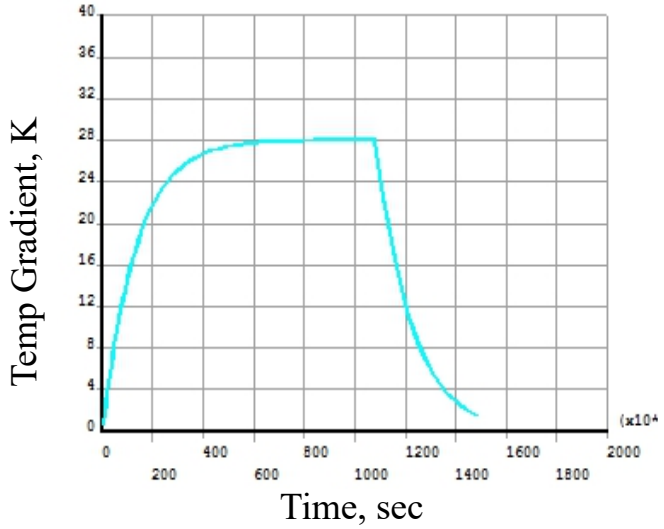
HB 650 Cryomodule: 70K Thermal Shield Design

30 Hrs Linear Cooldown of Thermal Shield

- Finger welds optimized for 40K gradient
- Variation of h with temperature considered
- Variation of properties with temperature
- Steady state temperature within 10K
- Max. Gradient = 28 K (complies with 40 K limit)
- Structural analysis at maximum gradient done



Steady state Temperature Distribution



Temp gradient V/s time

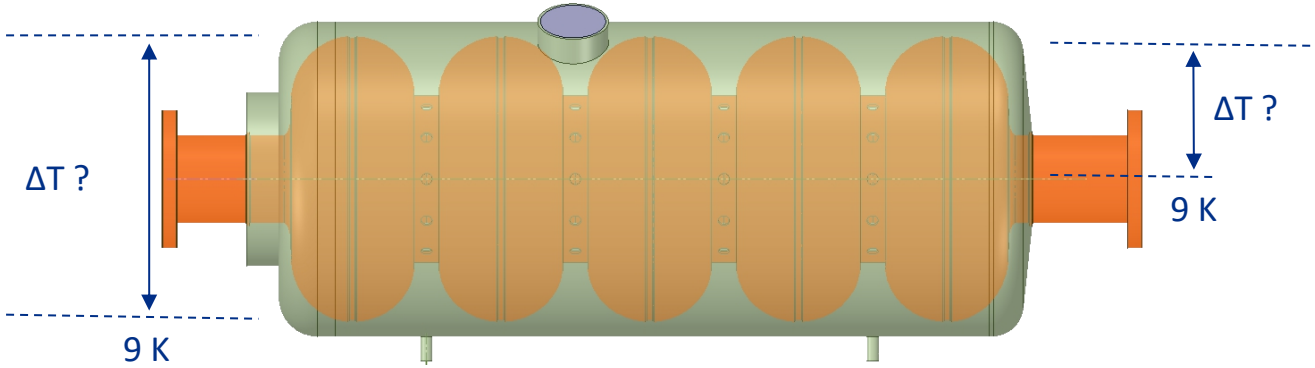
Fast Cooldown Analysis of 650MHz Cavity

Topic:

Simulation of the cavity transient temperature during fast cool down process.

Boundary conditions:

- Initial condition is 45 K uniform on the cavity and helium vessel.
- Inlet 2-phase flow 4.8 K.
- Quality of 2-phase flow 10%



650 MHz cavity with helium vessel

Parameters to show the cavity temperature profile:

2-phase flow rate initially 12 g/s and then study for 4 g/s, 6g/s, 8 g/s, 12 g/s and 16 g/s

End Goal:

- To find the time for cavity bottom equators reaches 9K from 45K starting temperature.
- To find average ΔT b/w top and bottom of equators, when average temperature of bottom equators reach 9K.
- To find average ΔT b/w mid and top of equators, when average temperature of mid equators reach 9K.

The goal is to have bottom of cavity at 9 K and top of the cavity at 17K within 2.5 minutes.

Fast Cooldown Analysis of 650MHz Cavity

Assumptions:

- Chimney positioned to the center plane of the cavity
- One Fourth Model using two symmetric planes

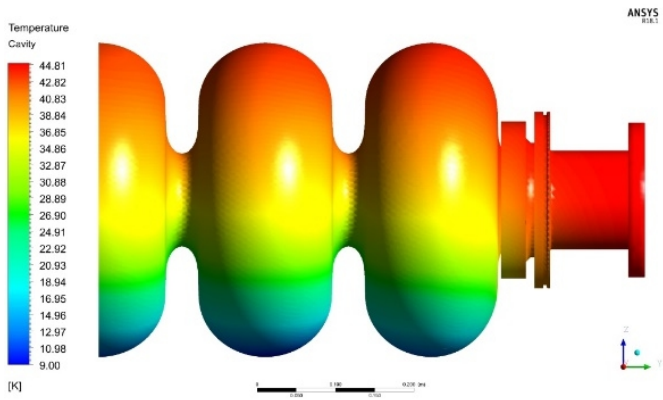
Results:

1) For mass flow rate of 12 g/s

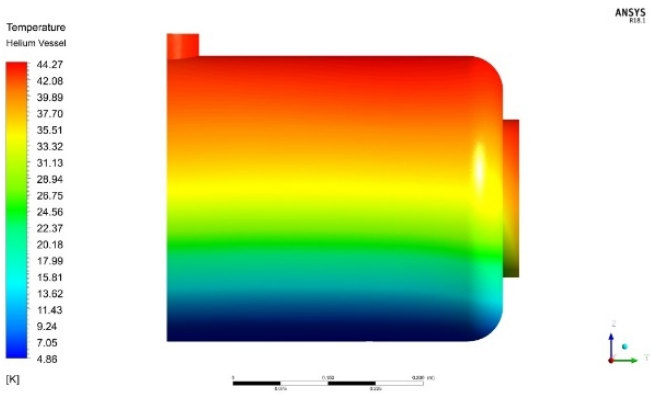
Simulation has been completed for ~180 s

- Cavity bottom reaches 9.17 K in 62 secs
- Cavity top temperature is 44 K
- ΔT = 35 K
- Helium Vessel has temperature ~4.8 to ~44.5 K

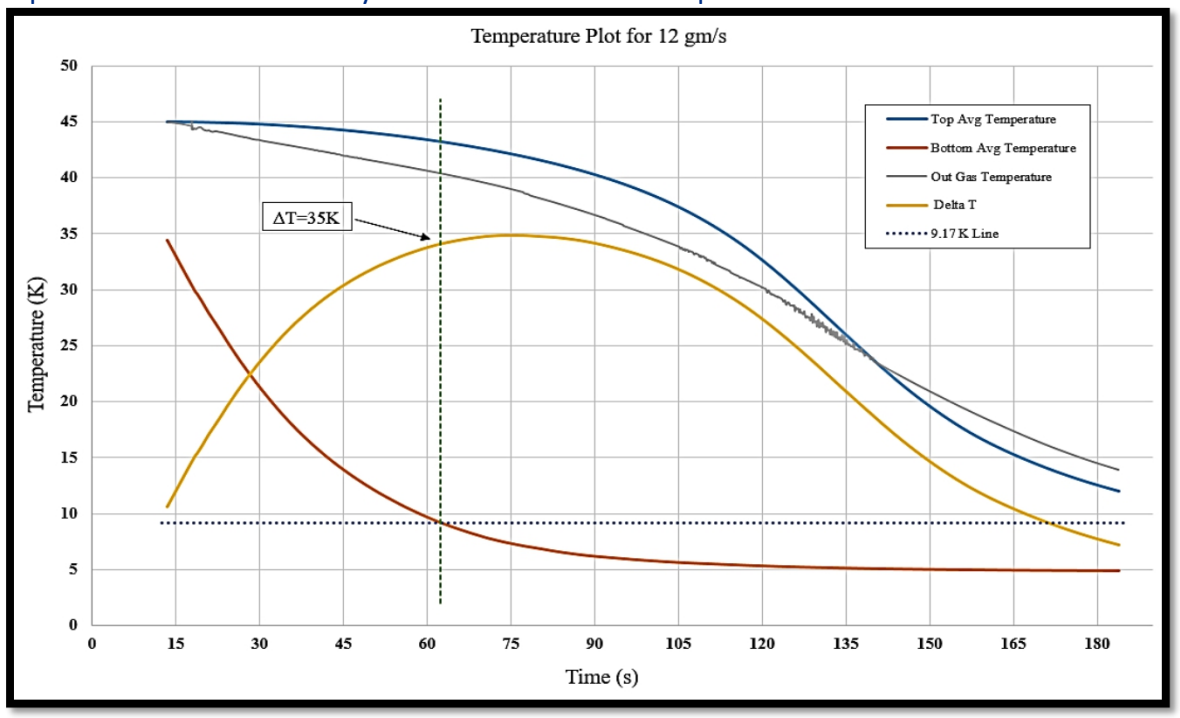
Flow Rate	Bottom Temperature	Top Temperature	Temperature Difference (ΔT)	Time
4 g/s	9.17 K	37 K	27 K	193 sec
6 g/s	9.17 K	43 K	34 K	126 sec
8 g/s	9.17 K	44 K	35 K	95 sec
12 g/s	9.17 K	43 K	34 K	62 sec
16 g/s	9.17 K	44 K	35 K	50 sec
Requirement	9.17 K	>17 K	>8 K	<150 sec



Temperature Contour of Cavity



Temperature Contour of Helium Vessel

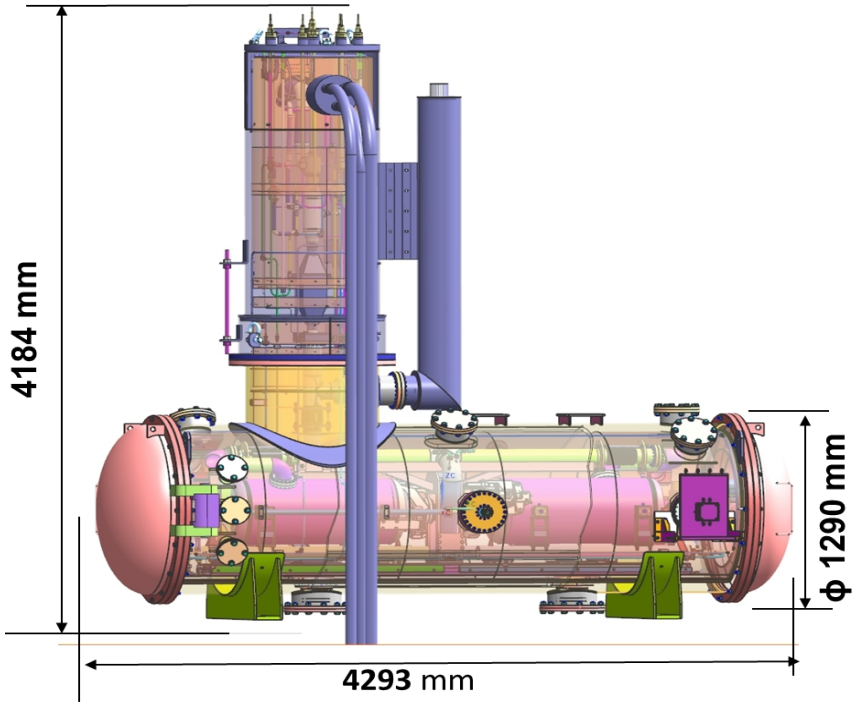


Temperature vs Time plot of Cavity

Design and Fabrication of HTS-2 Cryostat

- Horizontal Test Stand (HTS) has been designed, fabricated, installed and commissioned.
- **HTS cryostat is very similar to a two cavity Cryomodule.**
- Highlights of HTS:

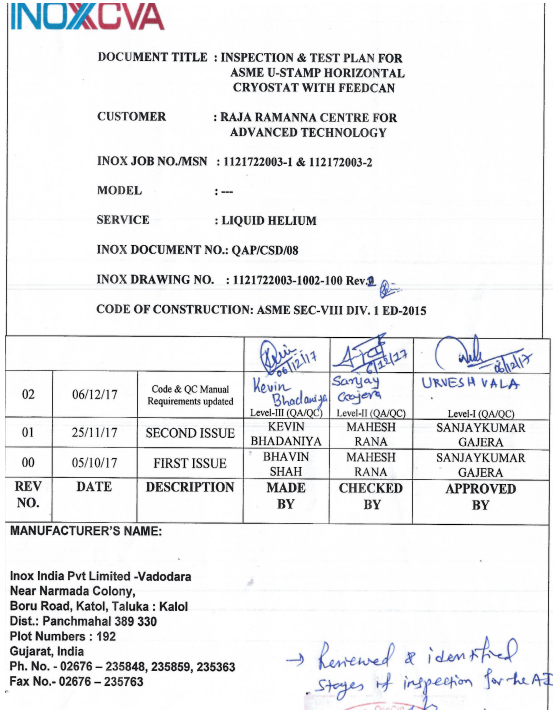
1. Designed with fermilab under IIFC collaboration
2. Vendor development for HTS done earlier
   will be very useful for Cryomodule
3. HTS is anyway an important part of SCRF cavity infrastructure
4. Fabrication has been carried out by M/s INOX India Pvt. Ltd. Vadodara, Gujarat,India



3-D Model of Horizontal Test Cryostat -2

Quality Assurance Plan (QAP)

- Comprehensive QAP meticulously planned & followed to ensure quality as per specs
- Detail Assembly Sequence Plan with Quality Check Points
- QAP & Fabrication Drawing Reviewed Jointly by RRCAT and Fermilab
- Inspection & Test Plan for ASME U Stamped Vessel for Cryostat & Feedcan
- Witness & Review after every stage fabrication for all subsystems



INOXCVA

DOCUMENT TITLE : INSPECTION & TEST PLAN FOR ASME U-STAMP HORIZONTAL CRYOSTAT WITH FEEDCAN

CUSTOMER : RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY

INOX JOB NO./MSN : 1121722003-1 & 112172003-2

MODEL : ---

SERVICE : LIQUID HELIUM

INOX DOCUMENT NO.: QAP/CSD/08

INOX DRAWING NO. : 1121722003-1002-100 Rev.2

CODE OF CONSTRUCTION: ASME SEC-VIII DIV. 1 ED-2015

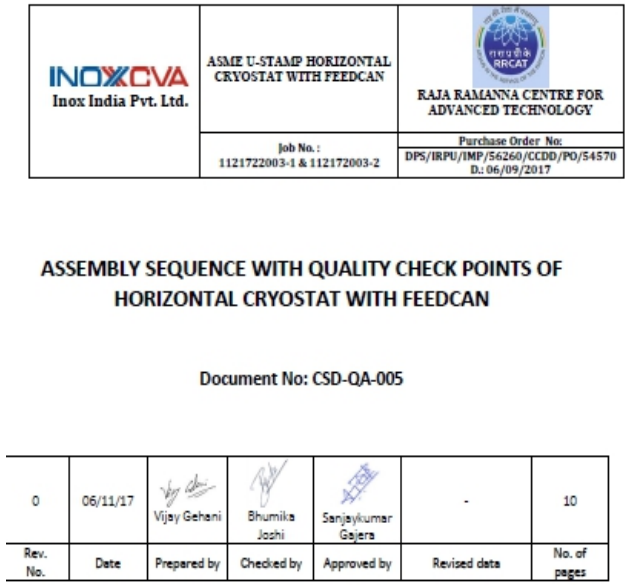
REV NO.	DATE	DESCRIPTION	MADE BY	CHECKED BY	APPROVED BY
02	06/12/17	Code & QC Manual Requirements updated	Kevin Bhadaniya Level-III (QA/QC)	Sanjay Gajera Level-II (QA/QC)	URVESH VALA Level-I (QA/QC)
01	25/11/17	SECOND ISSUE	KEVIN BHADANIYA	MAHESH RANA	SANJAYKUMAR GAJERA
00	05/10/17	FIRST ISSUE	BHAVIN SHAH	MAHESH RANA	SANJAYKUMAR GAJERA

MANUFACTURER'S NAME:

Inox India Pvt Limited -Vadodara
Near Narmada Colony,
Boru Road, Katol, Taluka : Kalol
Dist.: Panchmahal 389 330
Plot Numbers : 192
Gujarat, India
Ph. No. - 02676 – 235848, 235859, 235363
Fax No.- 02676 – 235763

→ Reviewed & identified stages of inspection for the AI

Detail Inspection & Test Plan



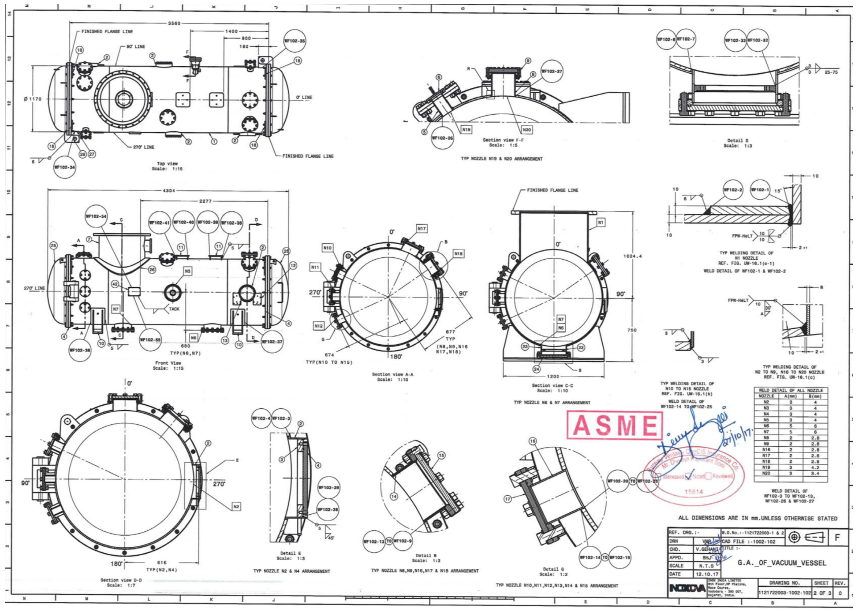
INOXCVA Inox India Pvt. Ltd.	ASME U-STAMP HORIZONTAL CRYOSTAT WITH FEEDCAN	RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY
	Job No.: 1121722003-1 & 112172003-2	Purchase Order No: DPS/IRPU/IMP/S6260/CCDD/PO/54570 D.: 06/09/2017

ASSEMBLY SEQUENCE WITH QUALITY CHECK POINTS OF HORIZONTAL CRYOSTAT WITH FEEDCAN

Document No: CSD-QA-005

Rev. No.	Date	Prepared by	Checked by	Approved by	Revised data	No. of pages
0	06/11/17	Vijay Gehani	Bhumika Joshi	Sanjaykumar Gajera	-	10

Detail Assembly Sequence



Review of Fabrication Drawing

Glimpses of Fabrication

Machining of Vacuum Vessel Ports

Feedcan Cryogen Circuit

Thermal Shield

Testing of Support Port Assembly

Assembly Sequence of Cryostat

HTS-2 Cryostat (April, 2019)

HTS Cryostat at INOXCVA

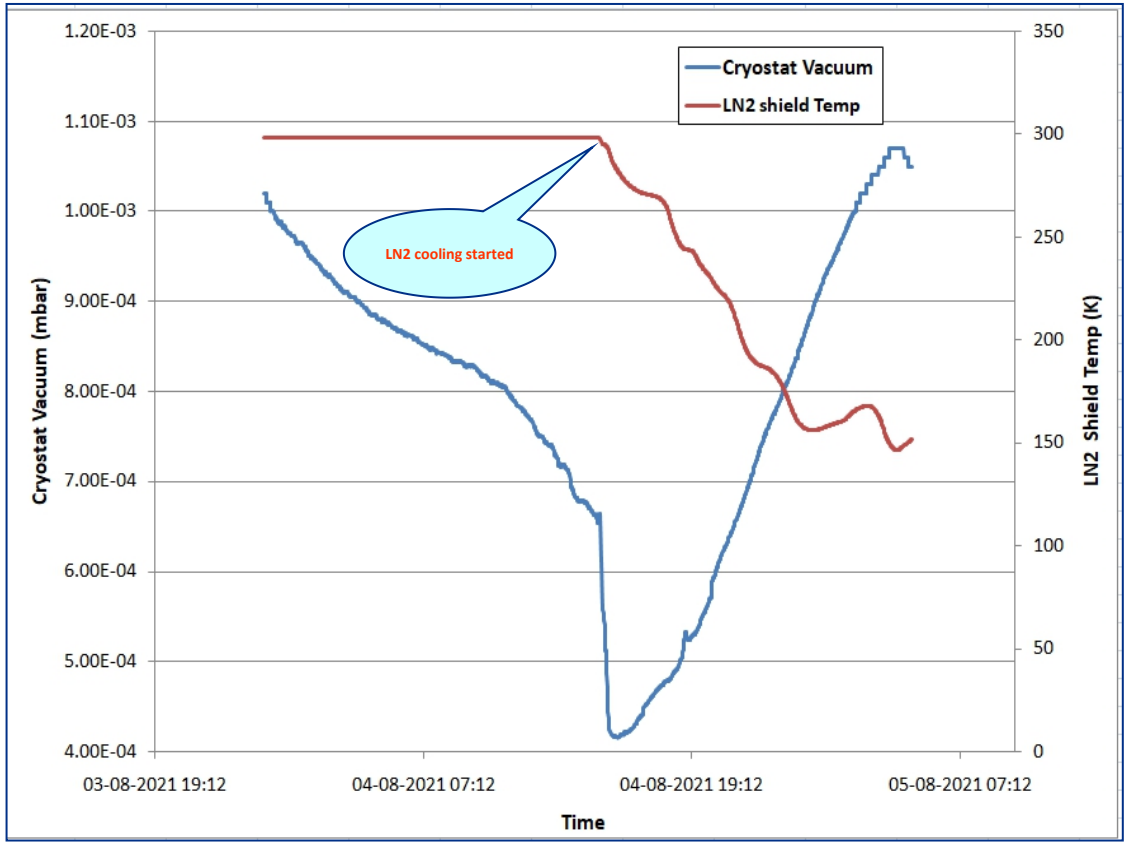
Integral helium leak rate of the order of 10^{-9} mbar.l/sec has been achieved at room temperature and at Liquid Nitrogen temperature as well.

HTS Cryostat Installed at RRCAT

Leak in Shield Cooling Circuit of HTS

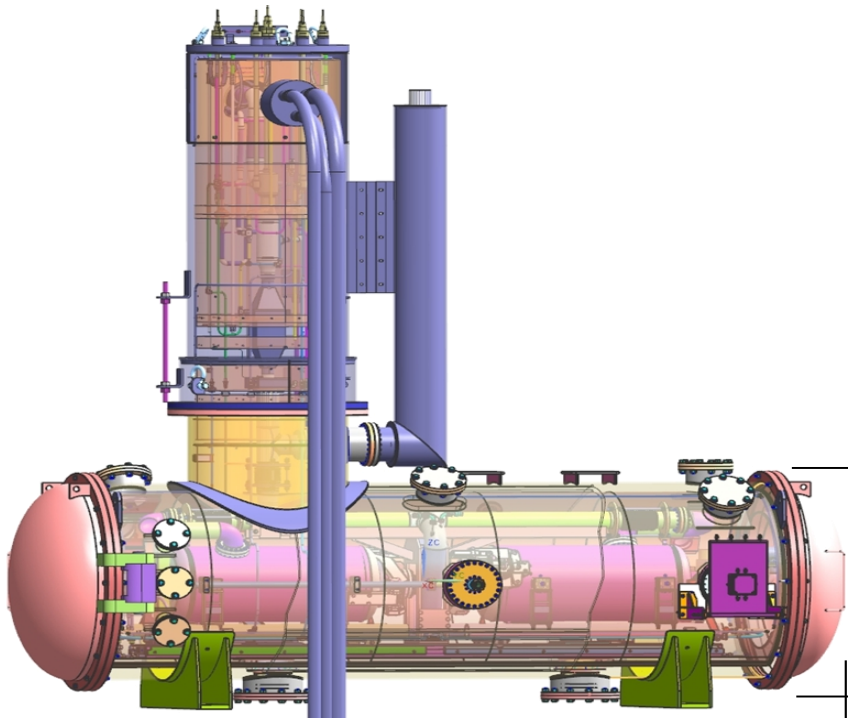
(After ~2.5 years after installation)

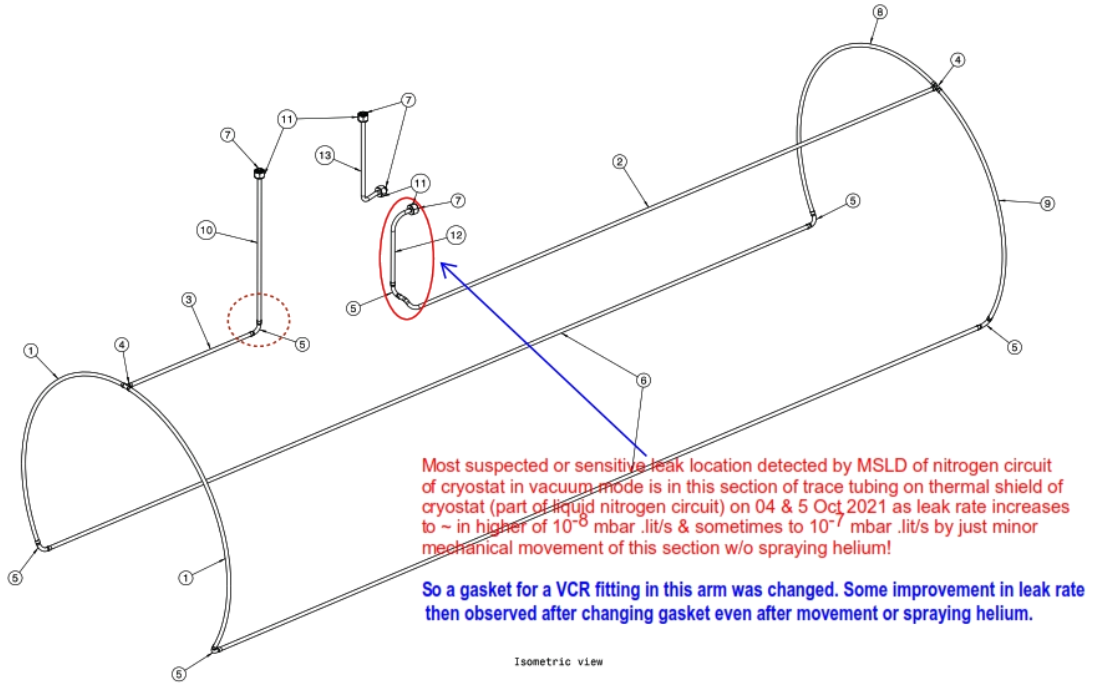
- On 04 August 2021, LN2 shield cooling of HTS cryostat was observed to trigger the degradation of vacuum
- As the shield cooling progressed, the vacuum started to degrade from 6.6E-04 mbar to 1.1E-03 mbar.
- Due to this degradation of the cryostat vacuum, LN2 supply was stopped on 5th Aug 2021 on 04:18 Hrs. After stopping the LN2 supply, the vacuum level of the cryostat started to improve.



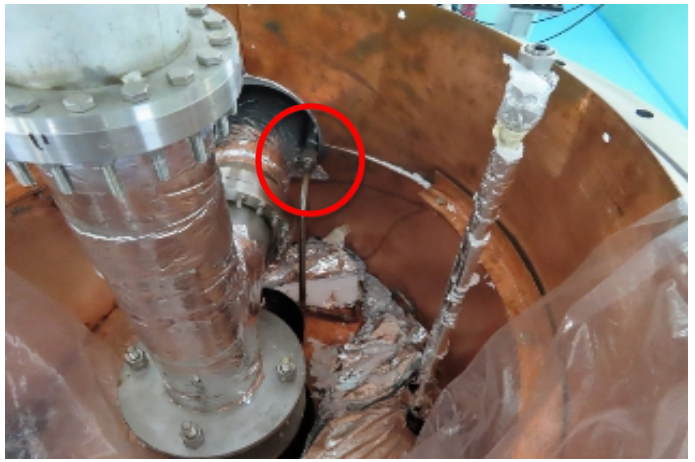
Leak rate of the order of 10^{-6} mbar.l/s persisted till room temperature

Leak in Shield Cooling Circuit of HTS





- Cryostat and feedcan were disaasembled and tested separately
- Leak was found in relief stack intercept VCR joint.
- Leak rate of **~2 x 10^{-8} mbar .lit/sec** without TMP was observed after repair



Phase-2 Preparation for cryomodule component fabrication and assembly

RRCAT Deliverables: HB CM Components

(After signing of Agreement)

- Vacuum Vessel
- Strongback and Cavity Support System
- Thermal Shield
- Piping and Mechanical Components (including Heat exchanger, Cryogenic valves, Cryo instrumentation)

No.	Year & Quarter	Milestones Falling in the Quarter
1.	2023-24 / Q1 (Apr-Jun 2023)	Close PRR for HB650 Cryomodule Strongback Support System Close PRR of HB650 Cryomodule Vacuum Vessel Close PRR for HB650 Piping and Mechanical Components
2.	2023-24 / Q4 (Jan-Mar 2024)	PO placement for HB650 Cryomodule Strongback Support System PO placement for HB650 Cryomodule Vacuum Vessel PO placement for HB650 Piping and Mechanical Components
3.	2025-26 / Q1 (Apr-Jun 2025)	Delivery of HB650 Cryomodule Strongback Support System Delivery of HB650 Piping and Mechanical Components
4.	2025-26 / Q2 (Jul-Sep 2025	Delivery of HB650 Cryomodule Vacuum Vessel

CM Assembly Infrastructure Development at RRCAT

Jacking system (Spreader Bar) for lifting cavity string Installed

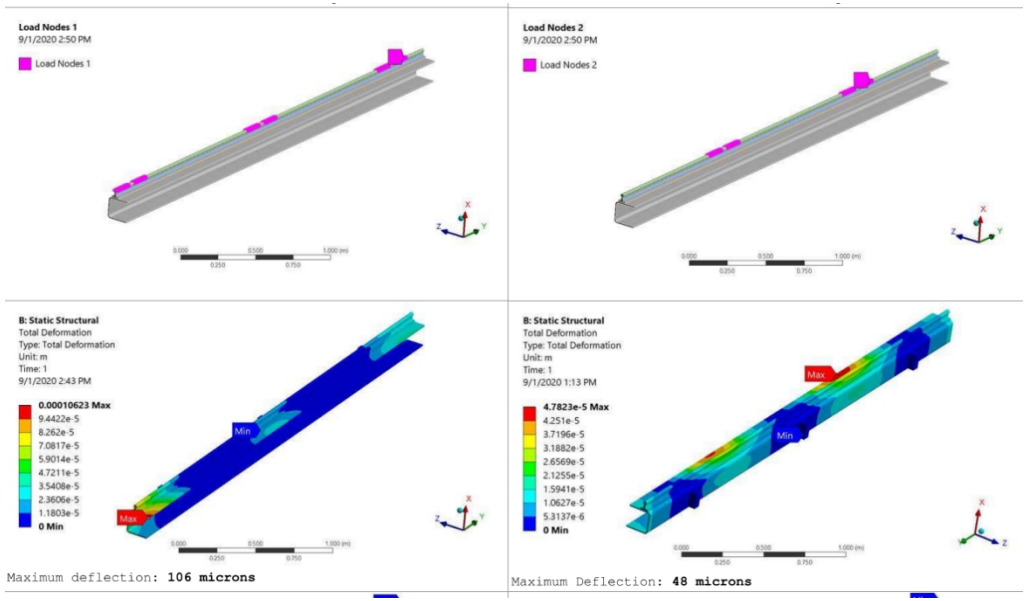
High Bay Area of CM Building **84m x20m**

Jacking system installed at high bay

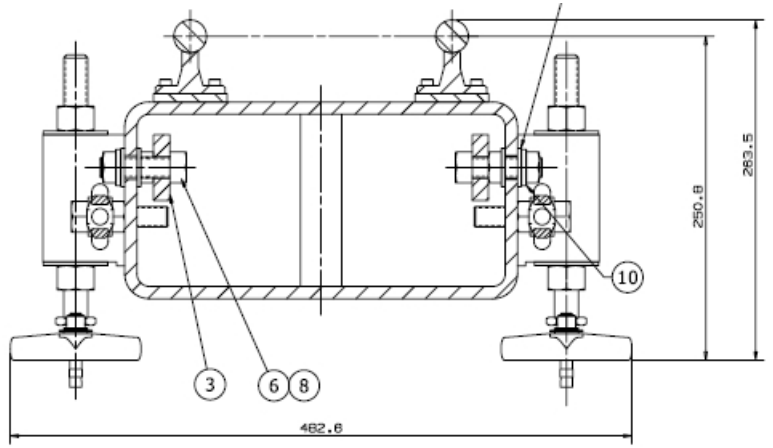
- Building is ready with EOT crane
- Capacity 6 Ton in Compression with 1m Stroke
- Translating, inverted type self locking worm gear screw jack (Make Powerjack)
- Speed range 30 to 300 mm/min at any desired intermediate speed with VFD control
- Overall Length 10 m with 1.6 m wide clear space between columns
- Minimum Height under the Beam 1.5 m (at lowest position)

Infrastructure Development: Assembly Rails

- 2D Drawings, Tech Spec for Rails & Linear Bearings prepared
- Probable Vendors contacted to get Budgetary Quotation
- Awaiting information from Fermilab on Acceptance Criteria and QC Document during installation & commissioning of the Rail system



Analysis of Rail Section and Calculations for Load Capacity Carried out



8” Wide Rail System Drawings

Vendor Development for HB CM Components

- To mitigate risk of possible delay in Procurement

  (HTS experience: Retendering required and PO placement delayed by ~12 months)

- Prepared Vendor Development & Discussions document (Not Procurement Document):
  - Document prepared based on Procurement Specification of HB650 pCM
  - 2D drawings prepared based on drawings of CM components from Teamcentre
  - Documents are solely used only for communicating to vendors about our requirement of Quality Assurance and Budgetary Estimation
  - Sharing of Quality Control document of recently fabricated pCM components by Fermilab will further ensure our move to mitigate risk
  - BOQ (Bill of Quantity) of pCM components is requested to share with RRCAT to get the details of bought out components like Flexhose, BellowsFittings, Cryogenic Valves, Bayonets, MLI, Cryo instrumentation, Connectors etc.

Vendor Development for HB CM Components Deliverables

Contacted two probable Indian vendors till now

- INOX India Pvt. Ltd. (successfully developed HTS cryostat)
- Vacuum Techniques Pvt Ltd

Minutes of Meeting with representatives from RRCAT Indore for discussion related to HB 650 MHz Cryomodule with M/S INOX India Pvt. Ltd.

June 21, 2022

Members:

Mr. Rajkumar Panjwani, Mr. Vijay Gehani, Mr. G C Tawanee, Mrs. Bhumika Joshi, Mrs. Dipali Vaidya, Mr. Kirit Patel, Mr. Sanjay Gajera, Mr. Ajay Sisodiya (Cryo Scientific Division – INOX India Pvt. Ltd.)

Mr. Shailesh Gilankar, Mr. Ankit Tiwari (CDCAS, RRCAT, Indore)

Minutes of Meeting for discussions related to fabrication of HB650 Cryomodule Components between RRCAT, Indore and M/s Vacuum Techniques Pvt. Ltd.

July 11, 2022

Members from :

M/s Vacuum Techniques Pvt. Ltd., Bengaluru : Mr. Y. Rangarao (Managing Director), Mr. Girish (Design Manager), Mr. Manohar (Production and Planning Manager)

CDCA Section, RRCAT, Indore : Mr. Shailesh Gilankar, Mr. Devendra Sinnarkar

Mr. Shailesh Gilankar and Mr. Devendra Sinnarkar, RRCAT have visited M/s Vacuum Techniques Pvt. Ltd., Bengaluru office and plant on July 11, 2022 for technical discussion related to complexity and requirements of HB 650 MHz Cryomodule components.

Inox India Pvt. Ltd.

INOX India Pvt. Ltd. is part of USD 3 billion Inox group of companies, with following capabilities:

ITER Cryolines, Cryogenic Systems for DAE and ISRO

- Inert Gas Supply Systems
- Cold Boxes for Cryo Process
- LH_2 Systems, LHe Cryostats & Systems
- Heat Exchanges & Cryogenic Coolers
- Cryolines for Cryogenic fluid handling
- Systems for cooling super-conducting magnets
- Superconducting magnets for MRI
- Storage systems for Liquid Hydrogen, Liquid Nitrogen and Liquid Oxygen
- Cryogenic propellant filling and servicing facility for Launch Pad project
- Development of Cryogenic Fluid Handling Systems
- Thermovacuum / Space Simulation Chambers

Vacuum Techniques Pvt. Ltd.

Vacuum Techniques Private Limited (VTPL) is manufacturer of vacuum equipment, vacuum chambers, vacuum pumps, instruments and components.

- Vacuum Chambers
- Vacuum Furnaces & Ovens
- Thermovac Systems & Dessicators
- Coating & Deposition Systems
- Vacuum Pumps & Pumping Systems
- Vacuum Components & Measurement Instruments
- Custom Engineered Vacuum Systems

Information Awaited

- Acceptance Criteria and Quality related documents for rail system
- Quality Control document of recently fabricated pCM components
- Travellers and other templates to follow
- Approved Drawings/Documents for Components to be Fabricated or Procured

Summary

- RRCAT with help of industry can manufacture components of HB650 CM
- Design Efforts for HB CM 70K thermal shield of R&D phase are over
- HTS-2 cryostat was designed in collaboration with Fermilab
- Indian industry M/S INOX India Ltd fabricated two numbers of HTS Cryostats
- One HTS cryostat has been installed & commissioned at RRCAT
- Leak developed in HTS Cryostat has been repaired and cavity tested
- Vendor development and discussion for HB CM components has been initiated

Thank You

Acknowledgement: J Ozelis, Vincent Rogers, Andy Hocker and IIFC Team