Bottom CRP Installation: Structural Modeling & Placement Tool

Ian Jentz, Yannis Pandiscas, Jon Stone December 5th, 2024



Agenda

- Mechanical Analysis of CRU installation
 - Floor Contact Modeling: looking at displacement of CRU during thermal contraction and frictional sliding on membrane floor
 - Thermal and Buoyancy modeling: looking at contraction of CRU structure and loads during LAr fill
- Positioning of CRU
 - Tool for final placement and adjustment of CRU on membrane floor

Floor Contact Model Summary

- We have implemented frictional contact between the membrane floor and the feet of the CRU.
- This will allow us to predict the stresses and any displacement or rotation of the CRU during cooldown.
- To test our boundary conditions, we ran the warm state deadweight load case with these new contacts. This is almost like what the first load case of cooldown
- The results with friction modelled are very similar to those using the fixed-frictionless support method:
- The fixed-frictionless support method is an acceptable simplification for when elastic boundary conditions are necessary.

Fixed-Frictionless Model Anode Z-Deformation – Friction Model Anode Z-Deformation







Floor Contact Model Setup

- Boundary condition representing the contact between supports and the membrane floor.
- rigid surface patches (about B, C, D, and E) represent the membrane floor. Remote displacements which don't allow these surfaces to move at all.
- Complex formulation of support/floor contact has frictional contact between surface patches and CRU support feet:
 - C has static friction coefficient of 0.34 representing aluminum and stainless steel.
 - B, D, and E are assigned 0.2 to represent stainless steel and stainless steel.
- A simple formulation of support/floor can also be used:
 - C is fixed condition
 - B, D, and E are frictionless contact



Floor Contact Model Vector Sum Deformation



B: Static Structural Total Deformation - Everything Type: Total Deformation Unit: mm Time: 1 s 11/25/2024 11:00 AM





Top Anode Z-Deformation

- Note the similarity in contours and magnitude between the complex model and simplified model.
- Deflection of the CRU and anodes is the same between complex and simple formulations of the membrane floor contact BC

Complex Model: Friction Modelled on all 4 supports







Top Anode Z-Deformation

- Note the similarity in contours and magnitude between the complex model and simplified model.
- Deflection of the CRU and anodes is the same between complex and simple formulations of the membrane floor contact BC

Complex Model: Friction Modelled on all 4 supports







BDE Z-Deformation

• Again, the BDE Z-displacements are similar between models.

Complex Model: Friction Modelled on all 4 supports







PEEK Spacer Stress

 Stresses are similar between models. 11.7-11.9 MPa peak is well within PEEK limits

Complex Model: Friction Modelled on all 4 supports







Composite Structure Stress

- These remain acceptable in the warm state, with a very healthy margin.
- These results will get more interesting during cooldown, but we predict that they will still be acceptable.







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FEMB Modelling And Density

- We have been using a bounding box approach to model the FEMBs.
- Within ANSYS there is a box of solid elements with approximate footprint of the FEMB.
- The updated mass of the FEMB is 0.6kg, from Manhong.
- The real volume of the FEMB is 204,300 mm3, this is the amount of LAr which will be displaced. This is used for the body acceleration calculations.
- Our ANSYS geometry has a volume of 796,420 mm3.
 We will use a different density than the physical density to model the mass correctly.
- Previous ANSYS models have had the FEMBs as 0.9kg, which is 1.5x heavier than reality.
- This is could be a good thing; it provides us with margin going forward.
- Which does the group want us to use going forward?



Representation	Density Value [kg/m ³]							
Physical Body Density	2937							
1.5x Real Mass ANSYS Geometry	1124							
Real Mass ANSYS Geometry	753.4							



G10 Adapter Plate Thermal Model Physical Properties

Material	ANSYS Model Density [kg/m ³]	ANSYS Model Secant Thermal Expansion Coefficient [1/K]	Poisson Ratio [-]							
G10	1850	0.988635 x 10 ⁻⁵	0.11							
Anode Composite	804	1.32 x 10 ⁻⁵	0.1543							
BDE Composite	1845.5	1.32 x 10 ⁻⁵	0.1543							
Composite Skin	1904	1.32 x 10 ⁻⁵	0.3065							
Composite Beams	1845.5	1.32 x 10 ⁻⁵	0.1543							
PEEK	1310	5.48 x 10 ⁻⁵	0.4							

These are 1.2×10^{-5} with a +10% added. The FEA analysis V2 document lists the CTE of the PCBs as 1.33×10^{-5} , which do we use?



G10 Adapter Plate Thermal Model Physical Properties

Material	ANSYS Model Density [kg/m ³]	ANSYS Model Secant Thermal Expansion Coefficient [1/K]	Poisson Ratio [-]
Stainless Steel	7960	1.388 x 10 ⁻⁵	0.27
Anode Composite	804	1.08 x 10 ⁻⁵	0.1543
BDE Composite	1845.5	1.08 x 10 ⁻⁵	0.1543
Composite Skin	1904	1.08 x 10 ⁻⁵	0.3065
Composite Beams	1845.5	1.08 x 10 ⁻⁵	0.1543
PEEK	1310	5.48 x 10 ⁻⁵	0.4

These are 1.2×10^{-5} with a -10% added. The FEA analysis V2 document lists the CTE of the PCBs as 1.33×10^{-5} , which do we use?



Comment About PEEK Thermal Expansion

- The value used in the CRP model and shown in the previous slides is 5.48 x 10⁻⁵.
- Looking at literature, I find an estimated value of 4.57 x 10⁻⁵.
 - ((10,000 500)/(295-87)) x 10⁻⁶.
- The value of the CTE for PEEK likely does not have a large effect in our model, but I wanted to be aware





Comment About PCB

- PCB CTE is described as orthotropic, with only the Y-direction matching the values that we have been talking about.
- Is the X-direction CTE different?

Orthotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion X direction	9.8E-06	C^-1
Coefficient of Thermal Expansion Y direction	1.2E-05	C^-1
Coefficient of Thermal Expansion Z direction	3E-05	C^-1



Thermal Model Approach

- We have tried to take the friction model from above and apply a thermal condition.
 - This model failed to converge after thousands of iterations spanning several days of computational time.
 - Debugging this model is impractical because of the solve time.
 - This model requires a lot of iteration as it must iterate displacement due to friction and iterate through displacement due to contraction. This interaction causes long solve times and impacts convergence.
- Instead, we will break this into two different models:
 - One model will investigate the slip along the floor induced by contraction; this was done by Josh Truchon at UW for the CRP. This model will include frictional contact, but the CRU will e treated as a solid rectangular box with the appropriate mass and CTE, elastic modulus and Poisson's ratio given to be those of the composite beams.
 - One model will investigate stresses caused by differential contraction within the structure of the CRU, this model will use elastic boundary conditions (fixed-frictionless) but include the real geometry of the CRU.



Slip During Cooldown Model



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Vector Sum Deformation





Deformation Along Long Axis





Friction Slip Model Summary

- This simple slip model behaves as expected and is likely sufficient to capture the information needed to inform design and installation procedure.
- We can extract the forces on the feet from the reactions on the floor, and input these into a stress model with the real geometry.
 - We have these but are working on making a visual.
- The reaction forces are similar in magnitude to those observed by Josh Truchon.
 - CRP Force Reaction Magnitude: 316 N
 - CRU Force Reaction Magnitude: 382 N
- We can insert the forces as remote forces in the full geometry model.



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CRU positions

R.		2	•		,				17		16		15		4	1	3		12		11		10		,				7				5		4		3		2		1
	10 ⁵⁸ 84	1496.0 mm	1496.0 mm	40 mm 1496.0 mm	1406.0 mm	1496.0 mm	40 mm	1496.0 mm	40 mm 1406.0 mm	40 mm 1496.0 mm	40 mm 1496.0 mm	4.0 mm 1496.0 mm	1496.0 mm	1496.0 mm	1496.0 mm	1496.0 mm	1406.0 mm	1496.0 mm	4.0 mm 1496.0 mm	4.0 mm 1496.0 mm	40 mm 1406.0 mm	1406.0 mm	1496.0	4.0 mm 1496.0 mm	4.0 mm 1456.0 mm	4.0 mm 1466.0 mm	4.0 mm 1496.0 mm	40 mm 1496.0 mm	1406.0 mm	1456.0 mm	1496.0 mm	1496.0 mm	1456.0 mm	1456.0 mm	1496.0 mm	40 mm	4.0 mm 1406.0 mm	4.0 mm 1406.0 mm	4.0 mm 1496.0 mm	40 mm 1496.0 mm	4.0 mm 1496.0 mm
337	0.0 mm	CRU 778 778L 778R	CRUTTA TTAL TTAR	CRU 73B 73BL 73BR	CRU73A 73AL 73AR	CRU 69B 69BL 69BR	CRU 69A 69AL 69AR	CRU 65B 65BL 65BR	CRU65A 65AL 65AR	CRU 61B 61BL 61BR	CRU 61A 61AL 61AB	CRU57B 57BL 57BR	CRUSTA STAL STAR	CRU 53B 53BL 53BR	CRU 53A 53AL 53AR	CRU 49B 49BL 49BR	CRU 49A 49AL 49AR	CRU 458 4581 4588	CRU 45A 45AL 45AR	CRU 41B 41BL 41BR	CRU 41A 41AL 41AB	CRU 37B 37BL 37BR	CRU37A 37AL 37AR	CRU338 338L 338R	CRU334 33AL 23AR	CRU29B 29BL 29BR	CRU29A 29AL 29AR	CRU258 258L 258R	CRU25A 25AL 25AR	CRU 21B 21BL 21BR	CRU21A 21AL 21AR	CRU 178 178L 178R	CRU 17A 17AL 17AR	CRU 138 138L 138R	CRU IBA 13AL 13AB	CRU 09B 09BL 09BR	CRU09A 09AL 09AR	CRU 05B 05BL 05BR	CRU 05A 05AL 05AR	CRU01B 01BL 01BR	CRU01A 01AL 01AR
337	9.0 mm	CRU 708 78BL 78BR	CRUTIA 78AL 78AB	0RU 748 748L 748B	0RU 74A 74AL 74AB	CRU 708 70BL 70BB	CRU THA 70AL 70AB	0RU 66B 66BL 66BB	0RU 66A 66AL 66AB	628L 628B	0RU 62A 62AL 62AB	0RU 508 588L 588R	ORUSIA SIAL SIAB	0RU 548 548L 548R	CRUSHA S4AL S4AB	CRUSOB SOBL SOBR	ORUSOA SOAL SOAB	46BL 46BB	CRU 46AL 46AL 46AB	0RU 428 428L 428B	0RU 42A 42AL 42AB	0RU 318 38BL 38BR	ORU 31A 38AL 38AB	CRU 34BL 34BR	244C	0RU308 30BL 30BR	0RU 30AL 30AL 30AR	0RU268 268L 268R	0RU26A 26AL 26AB	ORU 228 228L 228R	CRU22A 22AL 22AB	0RU 108 188L 188R	ORU 18A 18AL 18AB	0RU 148 148L 1488	CRU 14A 14AL 14AB	0RU 108 10BL 10BB	0RU 10A 10AL 10AB	0588	OFAL 05AL	028L 028R	ORU 02A 02AL 02AB
337	0.0 mm	CRU 798 798L 798R	CRU 79A 79AL 79AB	CRU 758 758L 758R	CRU75A TSAL TSAB	CRU 718 718L 718R	CRU 71A 71AL 71AB	CRU 67B 67BL 67BR	CRUSTA STAL STAR	CRU 638 638L 638R	CRU 63A 63AL 63AR	CRU59B 59BL 59BR	CRU59A 59AL 59AB	CRU 558 558L 558R	CRU55A 55AL 55AR	CRU51B 51BL 51BR	CRU51A 51AL 51AB	CRU 478 478L 478B	CRU 47A 47AL 47AB	CRU43B 43BL 43BR	CRU 43A 43AL 40AB	CRU 398 398L 398R	CRU39A 39AL 39AB	CRU35B 35BL 35BR	CRU354 35AL 35AB	CRU31B 31BL 31BR	CRU31A 31AL 31AB	CRU278 278L 278R	CRU27A 27AL 27AB	CRU 238 238L 238R	CRU23A 23AL 23AB	CRU 198 198L 1985	CRU 19A 19AL 19AB	CRU 158 158L 158R	CRU 15A 15AL 15AB	CRU 11B 11BL 11BB	CRU11A 11AL 11AB	CRU 07B 07BL 07BR	CRU 07A 07AL 07AB	CRU 03B 03BL 03BR	CRU03A 03AL 03AB
337	5.0 mm	CRU 80B 10BL 10BR	CRU SBA SOAL SOAR	CRU76B 768L 768R	CRU 76A 76AL 76AR	CRU 72B 72BL 72BR	CRU 72A 72AL 72AR	CRU68B 60BL 60BR	CRU68A 68AL 68AR	CRU 64B 64BL 64BR	CRU 64A 64AL 64AR	CRU 60B 60BL 60BR	CRU 60A 60AL 60AR	CRUS6B S6BL S6BR	CRUSEA SEAL SEAR	CRU52B 52BL 52BR	CRU52A 52AL 52AR	CRU 488 488L 488R	CRU 48A 48AL 48AR	CRU 44B 44BL 44BR	CRU 44A 44AL 44AR	CRU 408 408L 408R	CRU 40A 40AL 40AR	CRU36B 368L 368R	CRU364 34AL 34AR	CRU32B 32BL 32BR	CRU32A J2AL J2AR	CRU28B 28BL 28BR	CRU28A 28AL 28AR	CRU 24B 24BL 24BR	CRU24A 24AL 24AR	CRU20B 20BL 20BR	CRU20A 20AL 20AR	CRU 16B 16BL 16BR	CRU 16A 16AL 16AR	CRU 12B 12BL 12BR	CRU 12A 12AL 12AR	CRU08B 03BL 03BR	CRU 08A 08AL 08AR	CRU 04B 04BL 04BR	CRU04A 04AL 04AR

- Simplified layout of FD is provided in spreadsheet
- Cryostat membrane floor layout is taken from 3D model from FD2 CAD. Membrane floor has not changed over versions
 - FD2 Complete 3D Assembly (Navisworks) ,
 - Doc id 2756552 v.7, with Released status, 2023-12-18, Adrien Parchet <u>https://edms.cern.ch/document/2756552/7</u>
 - Doc id **3170306 v.8**, with In Work status, 2024-10-03, Adrien Parchet <u>https://edms.cern.ch/document/2756552/8</u>
- Bottom CRU layout is changed

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- 4mm spacing between CRUs in X
- Keep spacing in Y the same as top CRP planes
- Layout is 6 mm longer in X than top CRPs, 3 mm at each end
- CRUs are labeled and the 4 adapter plates / frames and their relative location are pictured
- Centroid (trihedral) position of CRUs are given relative to the center of the FD cryostat floor

Row		20				19				18		
	E E	шш	E	un m	E	шш	E E	u u u	E	mm	ш Ш	шш
intra CRU gaps	1496.0	4.0	1496.0	4.0	1496.0	4.0	1496.0	4.0	1496.0	4.0	1496.0	4.0
	CRU 77B		CRU 77A		CRU 73B		CRU 73A		CRU 69B		CRU 69A	
3370.0 mm	77BL		77AL		73BL		73AL		69BL		69AL	
	77BR		77AR		73BR		73AR		69BR		69AR	
5.0 mm												
	CRU 78B		CRU 78A		CRU 74B		CRU 74A		CRU 70B		CRU 70A	
3370.0 mm	78BL		78AL		74BL		74AL		70BL		70AL	
	78BR		78AR		74BR		74AR		70BR		70AR	
10.0 mm												
	CRU 79B		CRU 79A		CRU 75B		CRU 75A		CRU 71B		CRU 71A	
3370.0 mm	79BL		79AL		75BL		75AL		71BL		71AL	
	79BR		79AR		75BR		75AR		71BR		71AR	
5.0 mm							-					
	CRU 80B		CRU 80A		CRU 76B		CRU 76A		CRU 72B		CRU 72A	
3370.0 mm	80BL		80AL		76BL		76AL		72BL		72AL	
	80BR		80AR		76BR		76AR		72BR		72AR	



Position of Bottom supports

- CRU is positioned relative to cryostat center
 - CRU 01A trihedral location: X = 28.2955 m, Y = 5.0650,
- Each CRU has 4 supports. Described as viewed from the TCO side during install:
 - LB, left adapter plate, back support
 - LF, left adapter plate, front support
 - RB, right adapter plate, back support
 - RF, right adapter plate, front support
- Support position is given relative to the CRU trihedron.

CRU 01A Ø1ALB 01ALF 01ARB XRF.





	Position r CRU Trihed	elative to dron (mm)
Support	х	у
01ALB	1114.5	885.0
01ALF	432.5	885.0
01ARB	1114.5	-815.0
01ARF	432.5	-815.0

Placement Tool: Design Goals



- Precise and reliable control of displacement for CRU.
- Ease of operation, incorporating user-friendly controls.
- As compact as possible
- Challenges include:
 - Limited space.
 - Alignment requirements.
 - Interfacing device with the wood floor.



Placement Tool: Overview and Functionality



- Extruded 8020 framework provides modularity and rigidity.
- Key components:
 - 1.
 - Clamps attach the device to the wood floor. Tie rods with clevis ends connect to CRU and transfer load. 2.
 - Turn buckle allows rotational adjustment, to ensure CRU is parallel. 3.
 - Ball screws for precise linear motion in X and Y. 4.



Placement Tool: Positioning a CRU



- Alignment Steps:
 - 1. Adjust Turn buckle for rotational adjustment, ensure CRU is parallel to neighbors.
 - 2. Adjust Y ball screw until CRU has 4 mm gap to row behind
 - 3. Adjust X ball screw until CRU has 4 mm gap to neighbor CRU



Placement Tool: Next Steps

- Prototyping Phase:
 - Develop and refine the design.
 - Iterating on concepts to address linear motion in x displacement.
- Design Flexibility:
 - Exploring multiple mechanisms for linear motion.
- Prototyping and Testing:
 - Scale up testing to larger and heavier objects to ensure structural and functional reliability.
 - Push around a mock CRU