Design of Muon Campus Full Flow Purifier for Varying Operational Conditions and Horizontal Shipping

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FERMILAB-POSTER-23-144-PPD-TD

CEC ICMC 23 HONOLULU JULY 9-13 HAWAII CONVENTION CENTER

C2Po1C-08

Background

The Muon Campus g-2 experiment requires stable helium supply at 5 K to the superconducting magnet. After a short period of operations, the pressure drop across the magnet's flow supply valve increases due to impurities, resulting in reduced excess capacity concurrently with drop in refrigerator expander efficiency. This requires periodic powering down of the magnet to allow for helium valve "flush" to remove accumulated contamination at the valve as well as warming up the refrigerator expander above 80 K to release contamination. A "mobile" purifier is used for this periodic process but only at 10% of total refrigerator flow such that the purification process is extended. After long duration of running, this purification procedure is required almost every two weeks to restore proper liquid helium supply to the magnet. This shows requirement for full flow purifier which can purify impurities from entire Muon Campus refrigerator system and mitigate existing impurities issue and associated experiment downtime.

Sizing of Purifier

Input parameters	Value	Units
Impurity adsorption level	2	ppm
Adsorber bed pressure	20	atm
Helium mass flow rate	240	g/s
Adsorber online time	180	days
L/D ratio	6	-

Result	Value	Units
Charcoal volume	34	ft^3
Adsorber length	144	inch
Adsorber diameter	24	inch

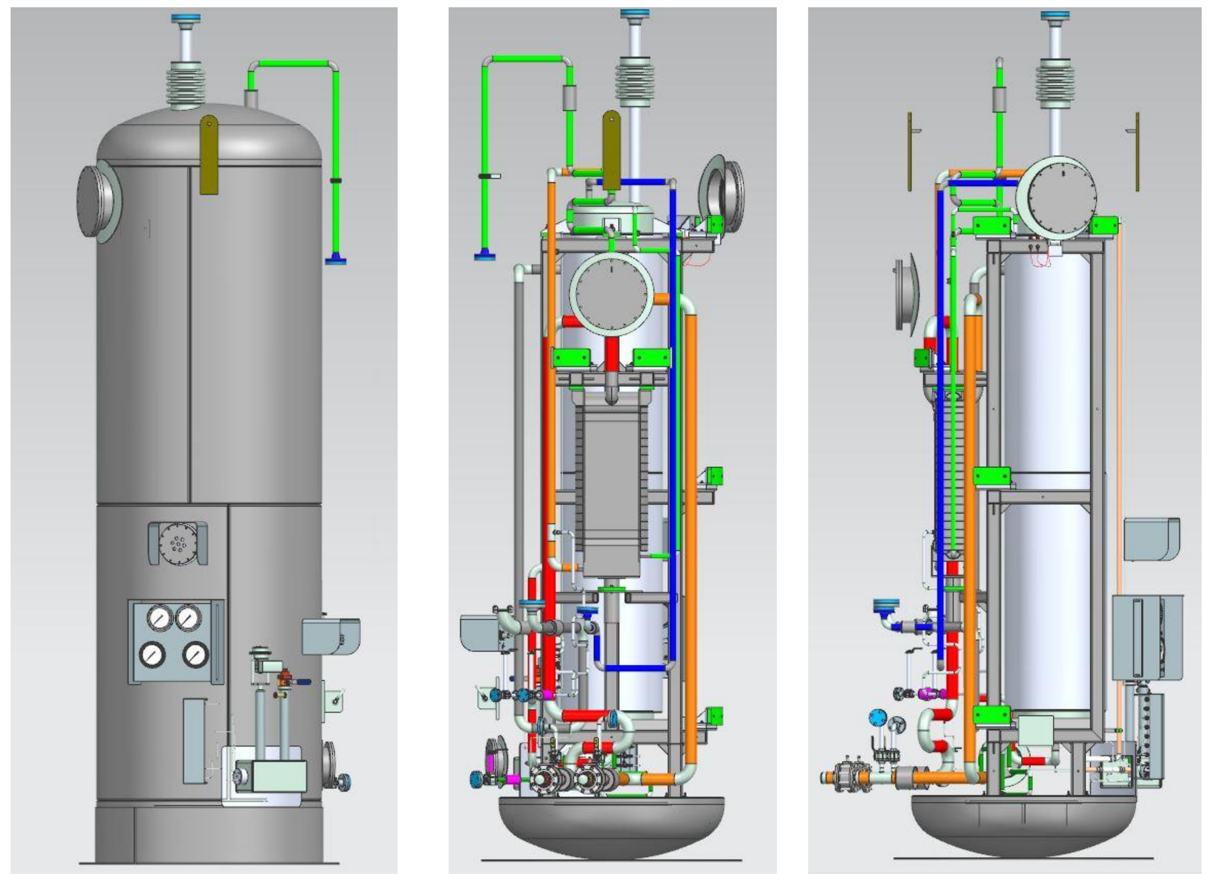

Figure 1: Final 3D model of purifier showing full assembly and internal view (Image courtesy: Ability Engineering Technology)

Specific adsorbent capacity of carbon is calculated on the basis of following equation.

$(\varepsilon_{ij})_{eq} = RT\ln(P_s/P)$ (Polanyi potential theory)

where,

R = Gas constant of Nitrogen (kJ/kg-K)

T= Temperature (K)

$P_s = Saturation\ Pressure$ (kPa)

P = Partial pressure of Nitrogen (kPa)

$(\varepsilon_{ij})_{eq}$ = Excess Adsorption Energy (kJ/kg)

Amount of charcoal required was determined from correlation between excess adsorption energy and nitrogen adsorbed by PCB and BPL carbon, extracted from Transactions of the 10th National Vacuum Symposium, 1963, Macmillan NY by Manes and Grant.

3D model for purifier was developed by Ability Engineering Technology (AET) based on specification and conceptual model from Fermilab.

FEA of Purifier

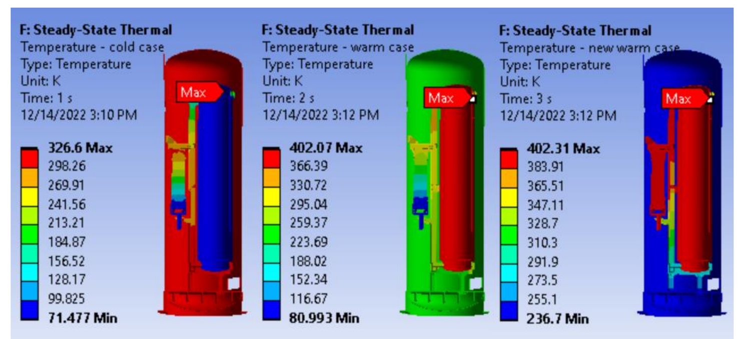

Figure 2: Temperature profile for cold and warm regeneration cases

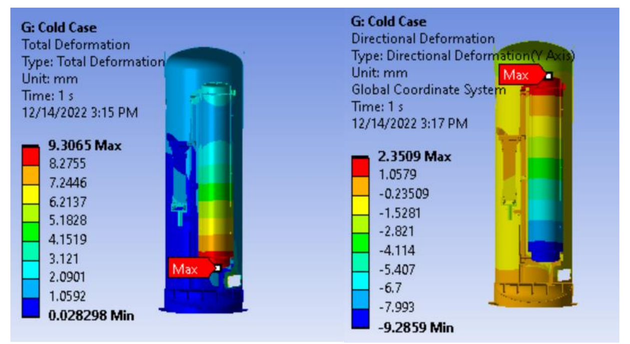

Figure 3: Deformation for cold operational case

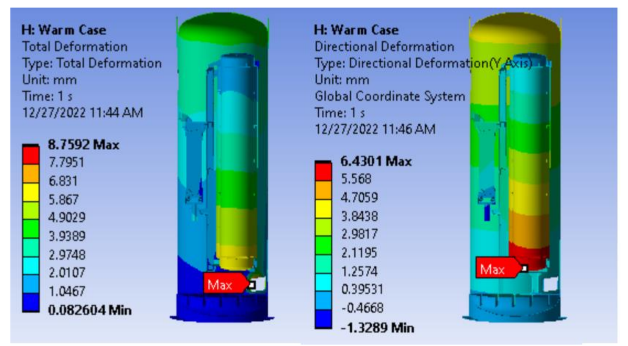

Figure 4: Deformation for warm regeneration case 1 for purifier.

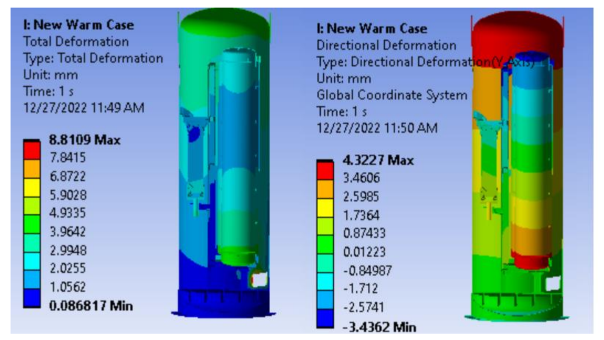

Figure 5: Deformation for warm regeneration case 2 for purifier.

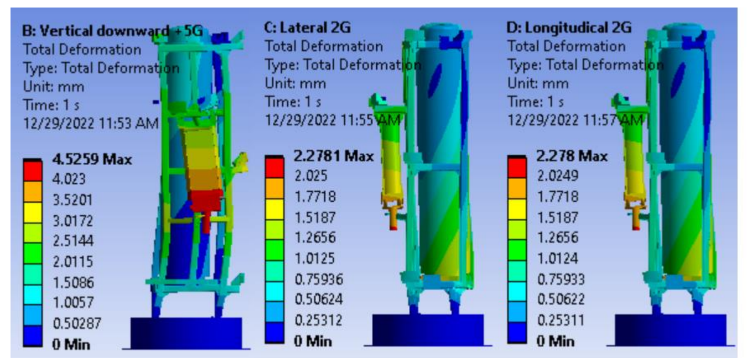

Figure 6: Deformation for 5g vertical, 2g lateral and longitudinal shipping cases

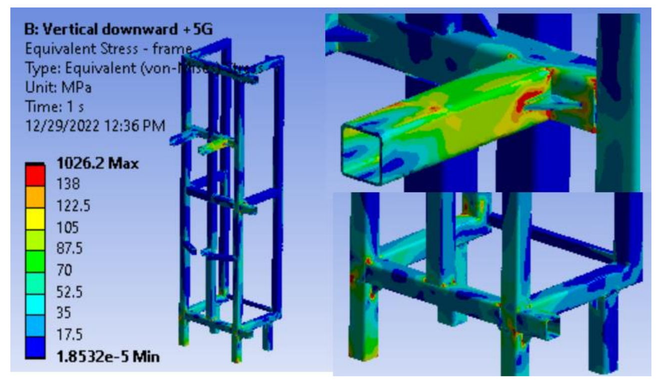

Figure 7: Max. stress location for vertical downward 5g shipping case

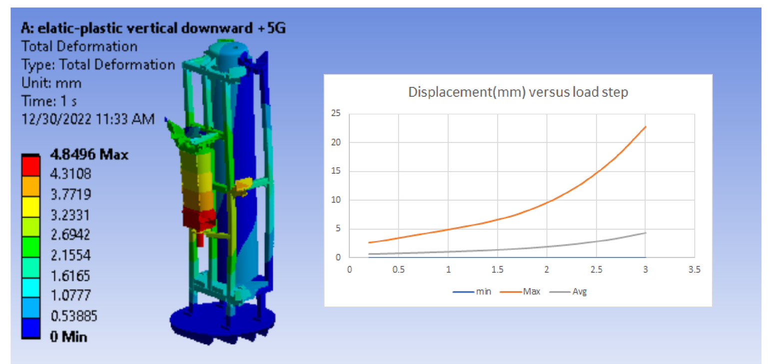

Figure 8: Max. average and min deformation profile of purifier for load steps

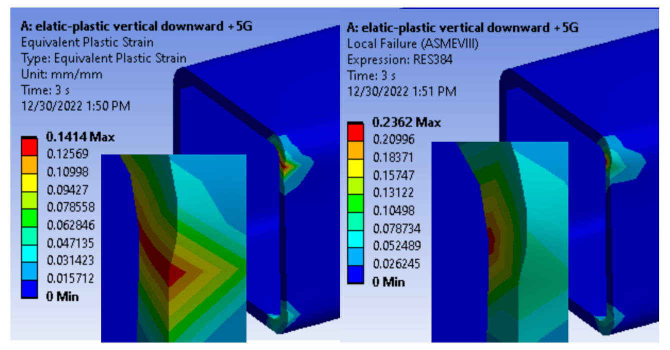

Figure 9: Local failure near maximum plastic strain in purifier

Temperature profile, maximum deformation and stresses were determined for cold and warm operational cases. Clearances between interacting parts were established based on FEA results for these cases.

Highest equivalent stresses and displacements were seen in 5g vertical load case for horizontal shipping. Elastic-plastic analysis was performed at 3 times the design load. 3 step loads at 5g, 10g and 15 g were applied. The solution converged which means there is no global plastic collapse. The maximum local failure ratio as per ASME BPVC VIII-2 section 5.3 is at acceptable value which shows no danger of local failure.

Modifications based on FEA

Several modifications were made in purifier in iterative basis in collaboration with AET to reduce displacement and equivalent stresses within acceptable limit. Heat exchanger being in offset position was generating high amount of stress and displacement in 5g vertical load case for shipping orientation. Heat exchanger stops were welded in vacuum vessel to restrict movement of the heat exchanger by restricting shipping pads.

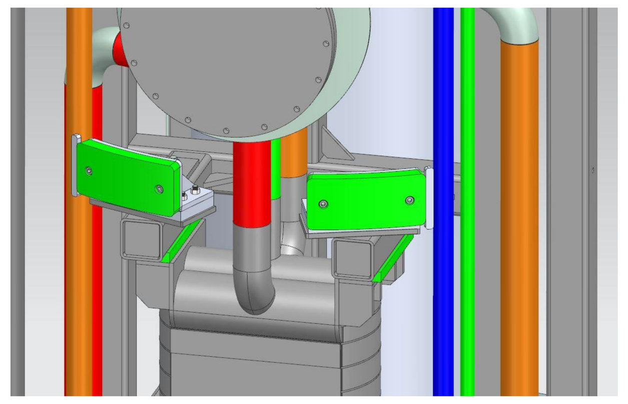

Figure 10: 3D model showing exchanger stops on shipping support pads

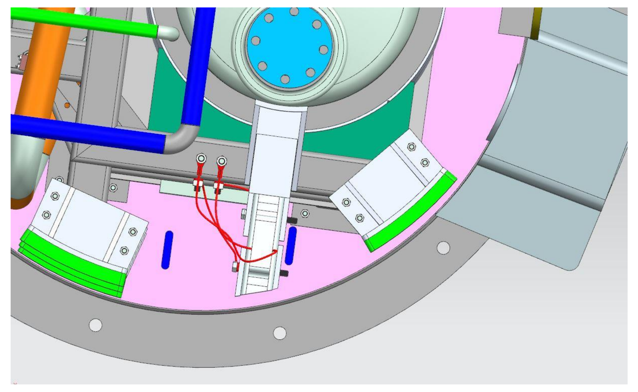

Figure 11: 3D model showing removable shipping support bar

Offset position of heat exchanger also caused entire heat exchanger frame to rotate. FEA analysis showed that additional support is required in top frame for 5g shipping load. Adsorber vessel support top frame is supported by removable shipping support bar which can be bolted to the vacuum vessel at one end and the support frame at the other end. A manhole was designed near this location to facilitate installation and removal of this shipping support bar.

Moments and resultant forces at all bolt locations were determined based on FEA analysis. The bolts were sized based on the resultant forces and moments at the bolt interfaces based on FEA. Use of FEA helped with improvisation of the design to meet the requirements for varying operational cases such as cold operation and regeneration and shipping cases.

Summary

FEA was used iteratively to resolve issues with operational and shipping cases of full flow purifier. Final Design Review is complete and fabrication of purifier is to be started.

Acknowledgement

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.