Mechanical Design and Analysis of LCLS II 2 K Cold Box

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Abstract— **The mechanical design and analysis of the LCLS II 2 K cold box is presented while highlighting its features and functionality. ASME B31.3 was used to check the design of its internal piping and further compliance of this code was ensured through a flexibility analysis. The 2 K cold box vessel was analyzed using ANSYS 17.2 to meet the requirements of the applicable codes, ASME Section VIII Division 2 and ASCE 7-1. Seismic and transportation loads were explicitly considered in both analyses.**

TABLE 1. Maximum Stresses of Flexibility Analysis

Mode	Type of Stress	Stress (MPa) [ksi]	Percentage of Allowable Stress
Transportation	Maximum occasional stress	60.5 [8.78]	33%
Normal Operation	Maximum sustained stress	7.52 [1.09]	5%
Normal Operation	Maximum expansion stress	29.7 [0.43]	14%
Normal Operation + Seismic Load	Maximum occasional stress	62.1 [9.01]	34%

TABLE 2. Seismic Load Calculation of Cold Box

Parameter	Value	Unit	Name
S_{DS}	1.968	g	Design Spectral Acceleration for short periods
S_{D1}	1.012	g	Design Spectral Acceleration for 1 sec
Ie	1	NA	Importance Factor
R	1	NA	Response Modification Factor
ρ	1	NA	Redundancy Factor
Ω_o	1	NA	Overstrength Factor
Cs	1.968	g	Seismic Response Coefficient
Q_E/W	1.968	g	Horizontal Seismic Design Force
ASD Loads – without Overstrength Factor			
E_h	1.968	g	Horizontal Seismic Acceleration
E_{h1}	0.590	g	30% Orthogonal Acceleration
E_v	0.394	g	Vertical Seismic Acceleration

TABLE 3. Basic Load Combinations (ASD) with Seismic Load Effect

Case No.	Code Requirement	Calculated (Q_E = 1.968 W, ρ = 1)
5	$(1.0 + 0.14S_{DS})D + 0.7\rho Q_E$	1.28D ± 1.38W (horizontal direction) ± 0.41W (30% orthogonal)
8	$(0.6 - 0.14S_{DS})D + 0.7\rho Q_E$	0.32D ± 1.38W (horizontal direction) ± 0.41W (30% orthogonal)

TABLE 4. Basic Load Combinations (ASD) with Seismic Load Effect

Stress Category	Pm	PL	PL + Pb	PL + Pb + Q
SA240, 304SS (MPa) [ksi]	138 [20]	207 [30]	207 [30]	414 [60]
SA516 Gr.70 (MPa) [ksi]	138 [20]	207 [30]	207 [30]	414 [60]

$(P_L + P_b) <= 1.5S$ (Paragraph 5.2.2.4(e), ASME Section VIII Division 2);
$(P_L + P_b + Q) <= 3S$ (Paragraph 5.5.6.1 (d), ASME Section VIII Division 2).
The 2K CB was analysed per PART 5—Design by Analysis Requirements—of ASME Section VIII, Division 2.

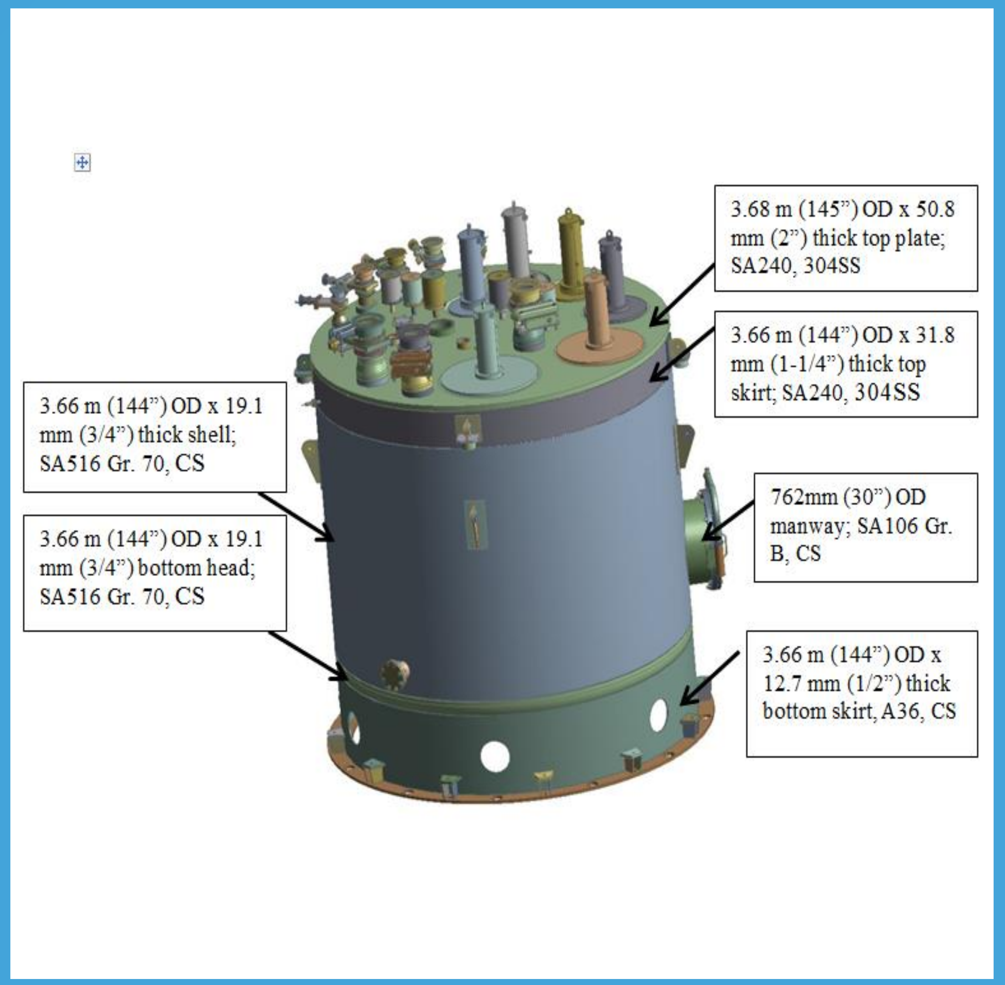

Fig. 1 LCLS-II 2 K cold box vessel. The 2 K cold box system is being designed at JLab. It consists of cryogenic cold compressors and the control system, vacuum jacket, internal piping, external utility piping, bayonets for cryogenic transfer lines and insulating vacuum pumps.

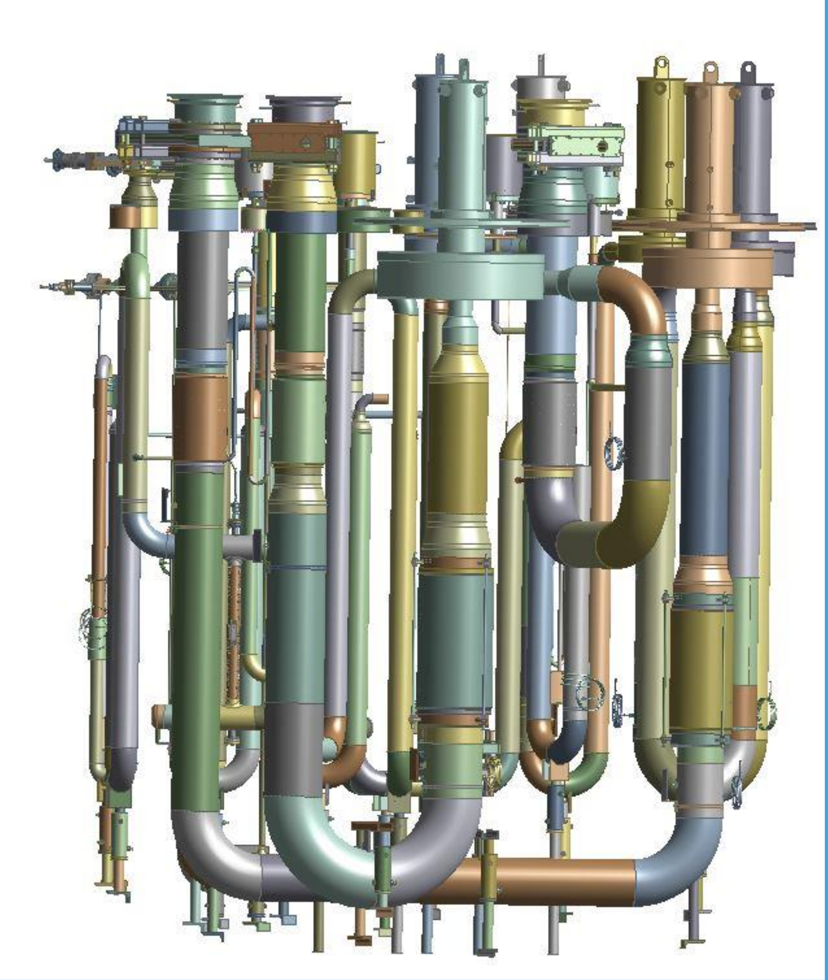

Fig. 2 Internal piping of cold box. All piping is designed in accordance with ASME B31.3-2014 Process Piping and local requirements. These local requirements include CBC, ASCE 7-10, and the Cryogenic Plant Seismic Design Criteria. AutoPIPE is used to perform flexibility analysis.

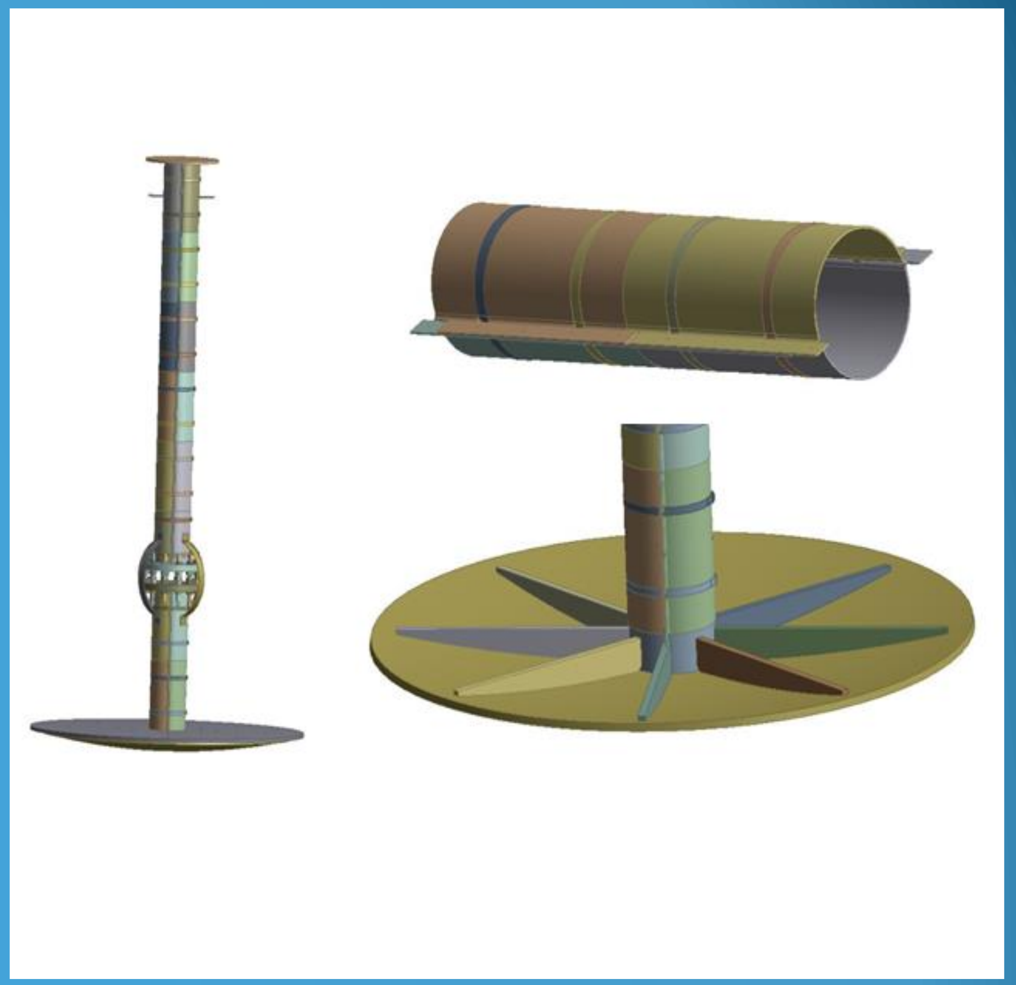

Fig. 3 Center Column Design. A center column is required to reduce the displacement on the top plate. It is made of two sections of 8 inch NPS Sch. 80 stainless steel pipe. Two sections are connected by tie rods and nuts for alignment purpose. To reduce its shrinkage, copper clamp shells are clamped to the outside surface of the center column. Plates and radical gussets are designed so that the load could be evenly distributed to the vessel.

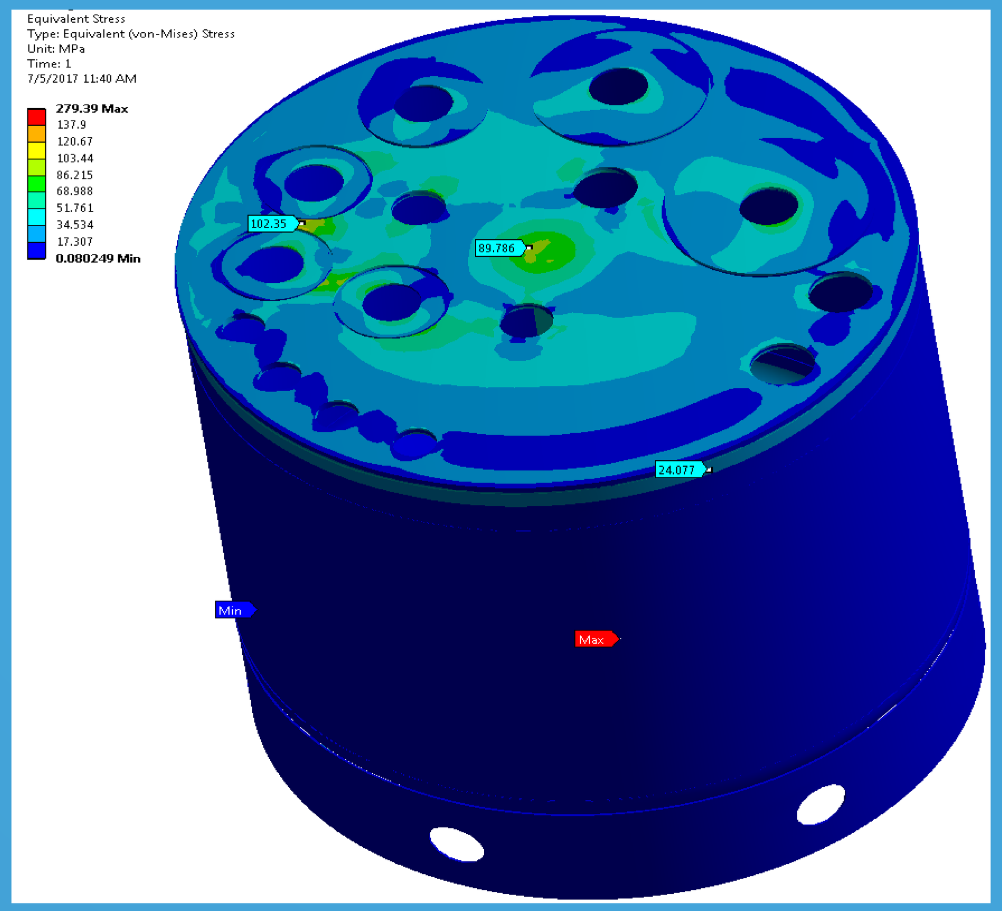

Fig. 4 Stress distribution. Both the stresses and displacements were found to be acceptable. Although the maximum displacement was 4mm (0.16 in) on the top plate, the relative displacement in each cold compressor area was less than the cold compressor supplier required tolerance (1.6mm). The maximum von-Mises stress on the vacuum vessel body was below the allowable stress

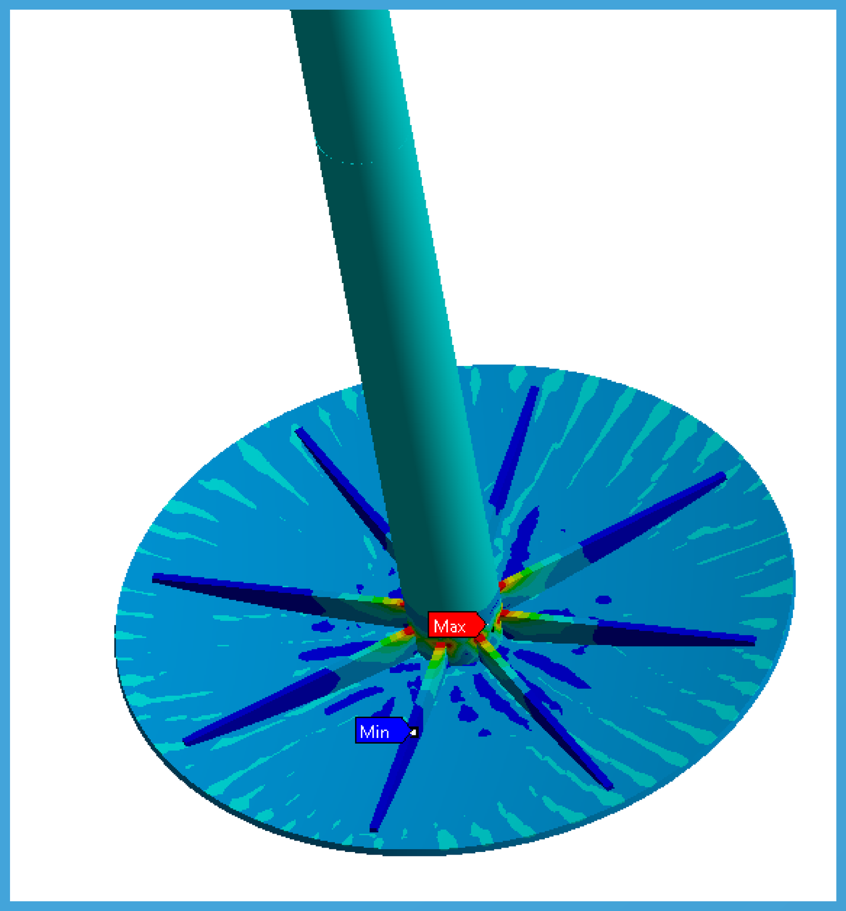

Fig. 5 Stress concentration. The overall stress of the center column was far below the allowable stress. Stress classification line (SCL) was created per ASME VIII Section 2. There were several points at which the sum of the primary local membrane stress plus primary bending stress was above the allowable stress, but the sum of the average membrane and primary bending stress was below the allowable stress. The local high stress on the center column was not a concern because it was due to stress concentration.

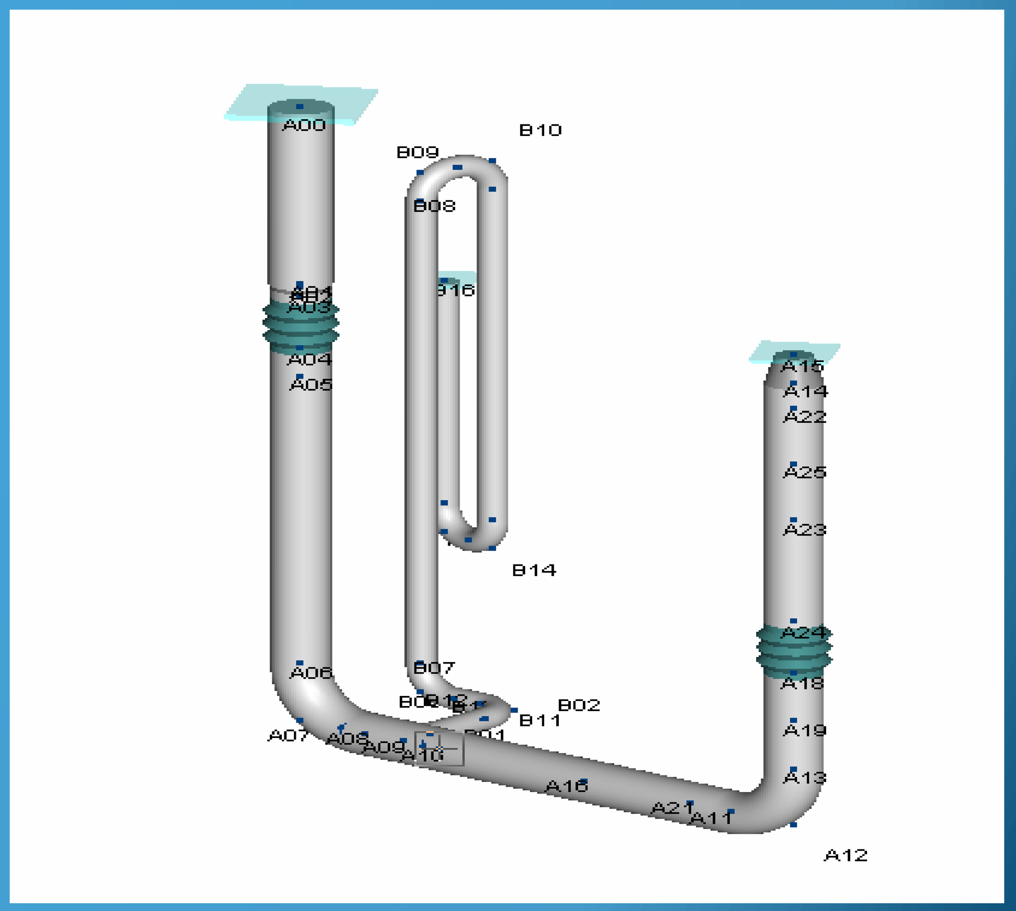

Fig. 6 AutoPIPE model of the section between bayonet and the CC2 inlet Nozzle for normal operation mode. The internal piping of the cold box was separated into 9 sections to simplify the analysis. Among them, the section between one of the three return flow inlet bayonets and the CC2 inlet nozzle has the highest stresses.

Conclusion - The design of the LCLSII 2K cold box and the internal piping system conforms to the code requirements specified in ASME VIII Divisions 1 and 2, ASME B31.3, ASCE7-10 and LCLSII seismic requirements. Although the partial penetration welds do not meet the ASME VIII Division 1 requirements including those: between the top plate and top skirt, between the top skirt and shell body, and between the shell body and bottom head; however, these welds were simulated and analyzed per ASME VIII Division 2and the design stress requirements from this division were satisfied.