Central Calorimeter
Thermal Gradient
Module Connection Analysis

D-Zero Engineering Note 3740.212-EN-102

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Approved PHWals

Introduction

Two 20 kW condensing and one 10 kW steady state cooling coils will be used to cool and condense gaseous argon in the Central Calorimeter (CC) Cryostat. Since this cool down (300K to 90 K) will inevitably cause shrinkage in the modules contained inside the cryostat, the connections between the modules have to be designed to withstand the increase in forces and moments induced by this contraction. This paper will present finite element analysis (ANSYS®) results to aid in the design or modification of the Central Calorimeter module connections.

Finite Element Models

Two Dimensional Model

A two dimensional ANSYS® half model (Figure 1) was first generated to estimate the connection forces between modules. Plate elements without bending stiffness (STIF 63 KEYOPT(1)=1) assembled into three 180 degree arches were used to estimate the end plates of the OH, FH, and EM arches. Isoparametric solid elements (STIF 45) were used to model the strap-beam assembly. Forces were transferred between arches by spacer elements (STIF 52) throughout the entire 180 degrees and between the OH arch to the strap-beam through an arc from 0 to 61.875. The beam was supported by one point (at 56.25 degrees).

Three Dimensional Model

The three dimensional ANSYS® quarter model (Figure 2) was generated to make the two dimensional results more realistic. Plate elements with bending stiffness (STIF 63 KEYOPT(1)=0) were used to model individual modules consisting of end plates and skins. These modules are linked together by coupled nodes (UX, UY, UX coupled, allows nodal rotation) in the end plate elements at the inner and outer radii of each arch. Figure 3 shows individual module connection. Isoparametric solid elements (STIF 45) were used to model the beam-strap assembly. Forces are transferred between arches by spacer elements (STIF 52) throughout the lower 90 degree section (See Figure 2). All of the spacer locations, module, beam-strap dimensions and support location are per BNL specifications. Table 1 shows a comparison between the two and three dimensional models.

Table 1 2-D Versus 3-D FEM Model

2-D	3-D
STIF 63 plate STIF 45 beam	STIF 63 plate STIF 45 beam
Just end plates	end plates,side,top,bottom skins
Solid ring of plate elements	Separate modules, coupled nodes
180 degrees arch support	90 degrees arch support
0 degree slope on OH arch	20 degree slope on OH arch
3-D Beam-Strap Support	Exact Beam-Strap per BNL
Support point on beam	Support off beam, exact location
OH-Beam Connection- 61.875°	OH-Beam Connection- 56.25°
Weight totally on end plates	Weight totally on end plates

Loads

Weight

All of the module weight is essentially transferred through the end plates of the modules in the actual structure; therefore, the weight of the module in the FEM model was placed on the end plates only. This was done by assigning appropriate densities to the endplates and applying a global acceleration. Approximately the same weight was placed on both the 2-D and 3-D arches (The time between the model generation of the two brought slight changes in the CC weight). Graphs 1-9 show a force and moment comparison between the 2-D and 3-D static load case. Figure 4 shows a generic end plate force diagram to be used in reference with the graphs.

Figure 1

1 2-D ENDPLATES, 3-D BEAM/STRAP

ANSYS 4.2B
JUL 28 1987
8:38:28
PLOT NO. 1
POST1 ELEMENTS

ORIG SCALING
ZV=1
DIST=98.6
XF=44.1
YF=-1.38
ZF=-22.3
HIDDEN

Figure 4 Force Diagram

The graphs clearly show a very similar trend in the forces for the three arches. Any differences are a direct result from the model contrasts stated in Table 1.

Thermal Gradient

To study the effects of cool down on the CC modules, a temperature gradient had to be added to the 3-D FEM model. Using the coordinate system given in Figure 2, the temperature profile in the Y (Vertical) direction is given in Figure 5.

Figure 5 Vertical Temperature Gradient

The figure shows a factor of 2 change in temperature from 150 K to 250 K throughout even increments of the CC's height. This temperature gradient is superimposed with constantly increasing temperatures in Z to 300 K (In effect making the center of CC at 300K). Graphs 10-18 and tables 2-4 show a 3-D comparison between the warm and cooled down cases. The only difference between the static 3-D case and the thermal case is the fact that spar elements (STIF 8) were used instead of spacer elements to transfer the load in between arches. The solution was iterated manually and any spar that went into tension at the end of an iteration was removed. Three iteration were required to produce the 'converged' condition where all spars were in compression. This technique was adopted because of convergence difficulties with the STIF 52 space elements.

Further Investigation

At the present, more work is being compiled to obtain a true or more realistic temperature gradient for CC, and to make the model as realistic as possible. When this is completed, other ANSYS® runs and similar graphs and charts will follow.

Conclusion

A 3-D model of the Central Calorimeter module structure was generated and successfully compared to an earlier generated 2-D model. A temperature gradient, that some what estimates the true cool down gradient, was added to the 3-D case. Graphs 9-18 show the cool down comparison. These graphs, along with graphs generated from future runs, can be used to help design or modify the module connections for the CC.

Figure 2

1 CENTRAL CALORIMETER ARC STRUCTURE

ANSYS .2B
JUN 24 1987
15:13:15
PLOT NO. 1
PREP7 ELEMENTS

ORIG SCALING
XV=1
YV=.5
ZV=1
DIST=98.6
XF=32.4
YF=2.8
ZF=-36.5
HIDDEN

Figure 3

CENTRAL CALORIMETER ARC STRUCTURE

ANSYS 4.2B
JUN 24 1987
15:13:30
PLOT NO. 3
PREP7 ELEMENTS

ORIG SCALING
ZV=1
DIST=98.6
XF=32.4
YF=2.8
ZF=-36.5
HIDDEN

X - Designated Axis

2-D Versus 3-D OH Normal Graph 2

2-D VS 3-D OH Moment **Graph 3**

Graph 4

2-D VERSUS 3-D FH SHEAR

Graph 5

Graph 6 2-D Versus 3-D FH Moment

Graph 7

Graph 8

2-D Versus 3-D EM Normal

Graph 9

	angle	OH SHEAR	OH Normal	OH Moment	OH Therm Norm	OH Therm SHEAR	OH Therm MOMENT
1	0	1367.617	-50705.03	13334	-48317.87	1317.87	2942.377
2	5.625	-6.729237	-46187.93	37181.04	-47594.03	385.8556	-4548.760
3	11.25	6148.409	-50144.97	-26068.15	-48718.93	7346.57	-33677.5
4	16.875	3789.570	-49513.78	-7452.67	-47592.63	4723.974	-5866.974
5	22.5	-5728.644	-48724.74	-7647.82	-46611.76	-3012.589	2074.535
6	28.125	-8172.757	-47116.45	-72202.51	-45468.43	-5433.797	-41492.6
7	33.75	-1092.859	-45255.26	-156422	-44596.4	2877.177	-105124.1
8	39.375	-13781.25	-42623.91	-187548.5	-41787.603	-9667.603	-105811.7
9	45	-19535.66	-39556.09	-318461	-38816.22	-16830.62	-206466.7
10	50.625	-17129.46	-36003.35	-482210.8	-35468.39	-17752.02	-351918.4
11	56.25	45909.91	-33242.89	-625898.6	-33582.54	45754.82	-497930.9
12	61.875	31368.47	-34421.54	-288906	-33670.17	31414.78	-160542.1
13	67.5	20632.44	-35865.65	-73440.07	-34989.05	19821.62	54705.03
14	73.125	16370.94	-36324.71	64093.28	-35557.18	15624.54	185384.5
15	78.75	12238.49	-35932.9	172369.1	-36103.85	11379.08	287382.9
16	84.375	8443.224	-34773.5	250158.7	-33998.87	7503.209	358724.1
17	90	4993.65	-33345.08	300547.7	-32521.4	4119.241	401162.2
18	95.625	1905.226	-31605.56	327279.3	-30747.35	1100.777	422160.1
19	101.25	-812.6415	-29679.58	332685.1	-29508.63	-1672.055	421446.8
20	106.875	-3118.084	-27377.68	317431.2	-26413.21	-4015.757	399530.1
21	112.5	-4986.899	-25016.95	286957.7	-23957.61	-5796.421	362305
22	118.125	-6430.078	-22576.33	244638.4	-21462.89	-7144.046	314527.4
23	123.75	-7462.856	-20156.42	193177.2	-19669.61	-8191.431	257685.1
24	129.375	-8078.77	-17673.65	134603.9	-16472.19	-8810.5	193452
25	135	-8295.251	-15341.06	73101	-14050.61	-8914.768	126629
26	140.625	-8142.801	-13119.04	11729.65	-11794.87	-8644.114	61409.97
27	146.25	-7655.362	-11120.39	-47764.54	-10391.81	-8142.181	-1819.712
28	151.875	-6863.172	-9322.604	-101861.4	-7919.959	-7328.722	-59424.78
29	157.5	-5814.93	-7841.81	-149508.3	-6387.121	-6150.27	-110366.0
30	163.125	-4554.251	-6597.324	-188239.6	-5129.264	-4756.167	-150839.2
31	168.75	-3126.66	-5712.925	-217873.4	-4853.512	-3297.608	-181974.8
32	174.375	-1587.745	-5178.687	-234710	-3677.847	-1726.029	-199884.2
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Graph 10

OH Normal Warm Versus Thermal

Graph 11

OH Shear Warm Versus Thermal

Graph 12

OH Moment Warm Versus Thermal

	Angle	3-D FH Normal	3-D FH Shear	3-D FH Moment	FH Normal Ther	FH Shear Ther	FH Moment Thermal
1	0	-54519.16	3573.691	58548.86	-54011.44	-.00046175	520293.8
2	5.625	-54456	1637.119	56428.6	-54937.22	-517.4983	514340.4
3	11.25	-54001.2	-5971.42	48234.2	-55722.82	-8234.742	491566.1
4	16.875	-49260.57	-3369.162	-90501.64	-55638.55	-9746.97	429035.4
5	22.5	-50894.78	-2247.729	-61223.94	-55298.14	-5836.406	361013.5
6	28.125	-47429.01	-10096.7	-125046.4	-53155.4	-8151.75	310926.6
7	33.75	-44747.32	-3920.015	-193862.8	-50846.46	-15238.16	250224.8
8	39.375	-41456.20	23400.49	-193353.3	-47701.7	-9268.768	152576.4
9	45	-42590.43	9427.624	-229526.9	-45073.82	2287.506	89900.12
10	50.625	-41640.51	17944.71	-83390.7	-42601.89	19047.49	91082.76
11	56.25	-41161.01	20773.12	-1398.415	-42304.77	13500.98	178056.8
12	61.875	-40570.81	16669.36	197855.7	-41585.22	17861.23	234216.6
13	67.5	-40947.63	21461.97	96134.01	-41552.94	20000.62	314993.9
14	73.125	-39756.1	12162.9	275179.9	-40707.76	15125.77	408334.7
15	78.75	-38468.74	7981.61	329804.7	-39728.2	10612.91	477820.5
16	84.375	-34544.66	-901.3032	369245.9	-38359.2	6437.228	523968.8
17	90	-36835.05	2501.471	363823.5	-36835.05	-939.7966	550270.2
18	95.625	-32037.92	-3834.116	358417.5	-33927.61	-4353.791	537102.7
19	101.25	-29311.89	-6288.026	333508.5	-31057.44	-7209.123	508474.7
20	106.875	-23466.71	-9735.372	251146.9	-28035.49	-9553.172	466030.8
21	112.5	-26480.63	-8261.065	297274.8	-25163.72	-11440.38	413203.3
22	118.125	-20491.84	-10709.95	198844.5	-21580.89	-12795.96	350247.7
23	123.75	-17570.18	-11206.83	142657.6	-18299.19	-13571.08	282330.9
24	129.375	-12130.86	-10872.29	27900.33	-15142.79	-13841.91	211499.4
25	135	-14791.96	-11254.35	84999.78	-12358.62	-13687.69	141145.7
26	140.625	-9734.301	-10095.18	-26234.16	-9249.565	-13073.57	71731.96
27	146.25	-7616.715	-8970.673	-75443.17	-6670.368	-12005.16	6961.276
28	151.875	-4380.022	-5883.864	-152349.5	-4415.388	-10573.68	-51682.69
29	157.5	-5835.099	-7550.516	-118243.8	-2655.782	-8867.432	-102043.2
30	163.125	-4380.022	-5883.864	-152349.5	-219.4897	-6993.695	-144375.9
31	168.75	-3323.463	-4026.625	-177326	1842.790	-4679.953	-173806.7
32	174.375	-2665.057	-2040.992	-192157	3680.929	-2130.302	-188477.4

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Graph 13

FH Normal Warm VS Thermal

Graph 14

FH Shear Warm Versus Thermal

Graph 15

3-D EM Normal 3-D EM Shear 3-D EM Moment

Angle EM Ther Norm EM Ther Shear EM Ther Momen

1	-8723.899	0	10642.47	0	-8740.320	0	4790.547
2	-8663.84	308.3270	8490.916	5.625	-8730.494	992.2937	2636.782
3	-8570.937	-872.3780	7459.268	11.25	-8653.178	-198.2199	4060.566
4	-8362.223	-2031.633	2192.209	16.875	-8561.031	-1373.812	1228.587
5	-7977.659	562.642	-7214.149	22.5	-8188.251	100.3726	-5847.717
6	-7852.185	323.844	-7143.254	28.125	-8067.937	125.2028	-7479.858
7	-7644.59	-727.134	-7854.297	33.75	-7786.538	-945.9307	-8965.44499
8	-7337.683	-1083.665	-12334.4	39.375	-7510.537	-1600.002	-14258.51
9	-6943.675	1927.036	-17966.13	45	-7009.246	3933.499	-21805.92
10	-6853.615	2021.778	-12622.03	50.625	-7171.107	3457.713	-9193.642
11	-6727.005	1153.502	-6824.855	56.25	-7126.479	2550.628	1718.432
12	-6523.021	2247.118	-4130.241	61.875	-7114.550	1675.117	9439.137
13	-6389.533	2126.933	2653.803	67.5	-6860.468	839.6414	14006.49
14	-6256.826	1391.513	9048.159	73.125	-6660.841	59.65497	15678.4
15	-6021.878	706.0264	12858.8	78.75	-6241.132	-658.9616	14571.67
16	-5738.541	78.18606	14316.15	84.375	-5874.96	-1360.9	11043.75
17	-5371.844	1172.219	13574.14	90	-5286.588	1640.571	5270.621
18	-5136.393	671.9427	16959.73	95.625	-5182.238	1137.413	10335.54
19	-4838.894	230.8832	18590.47	101.25	-4886.115	689.8684	13636.6
20	-4524.985	-147.7334	18781.62	106.875	-4660.758	299.8494	15485.3
21	-4170.552	-461.8583	17663.2	112.5	-4302.06	-29.69941	15956.84
22	-3815.884	-710.5324	15569.85	118.125	-4036.367	-298.0377	15408.32
23	-3441.998	-894.3359	12648.11	123.75	-3655.363	-505.3907	13929.16
24	-3083.884	-1014.519	9207.206	129.375	-3380.605	-652.9645	11866.91
25	-2726.673	-1074.158	5414.638	135	-3011.22	-743.309	9314.773
26	-2399.903	-1076.601	1521.577	140.625	-2761.458	-779.8805	6580.543
27	-2091.814	-1027.063	-2289.305	146.25	-2434.854	-767.1794	3760.175
28	-1826.612	-930.7791	-5845.13	151.875	-2239.107	-710.2961	1098.925
29	-1594.447	-794.6413	-8961.315	157.5	-1980.942	-615.6307	-1314.718
30	-1414.632	-625.4450	-11551.83	163.125	-1862.215	-489.6722	-3309.309
31	-1277.928	-431.2152	-13448.59	168.75	-1691.183	-339.9564	-4818.498
32	-1199.489	-219.8748	-14650.48	174.375	-1664.96	-174.03	-5746.002
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Graph 16

EM Normal Warm Versus Thermal

Graph 17

EM Moment Warm Versus Thermal

Graph 18

EM Shear Warm Versus Thermal