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Summary of FEA Calculations of STAR Support Rings*

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Introduction

Several FEA analyses of the STAR EM support rings have been performed. The original design was a continuous ring with a "C" channel cross section as shown in Figure 1. These rings were 2-3/4" thick with the center rings being only 1-3/4" thick. Based on the early analysis of these rings, it was determined that a continuous ring with a solid cross section should be used. This concept can be seen in Figure 2.

A thermal and mechanical analysis of both cross sections was performed. Because of symmetry, only half of the rings were modeled. The gravity load of the EM was applied to the ring by a rigid bar that extended radially from the location of the Thompson rails on the ring to the center of gravity of the EM module (see Figure 3).

In this paper we will first describe the analysis of the rings with the "C" channel cross section. The mechanical and thermal analysis of the thick 2-3/4" ring will be described, followed by the mechanical and thermal analysis of the thinner 1-3/4" ring. In the second section, the analysis of the rings with the solid cross section will be described. Once again the thermal and mechanical analysis of the thicker 2-3/4" ring will be first followed by the description of the thinner 1-3/4" ring.

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Analysis of the "C" Cross Section Rings

2-3/4" Rings

The 2-3/4" thick rings were first analyzed. A mechanical analysis of the ring was performed in which only the loading from the EM modules, and the weight of the ring was applied.¹ Next, the ring was analyzed using the additional thermal load imparted to the ring by an assumed 20° Fahrenheit temperature rise induced in the ring.¹

The initial mechanical analysis of the 2-3/4" rings found a maximum stress of 2,307 psi that occurs where the ring is supported at the bottom. The average stress throughout the ring is approximately 250 psi. The displacements of the ring, where the EMC modules are connected, are listed in Table 1 of the Appendix. Module number 1 is at the top of the ring at the 12 o'clock position and module number 30 is at the bottom of the ring in the 6 o'clock position. Displacements are in the Z (beam) direction and in the vertical direction. The maximum z direction displacement was .007" and the maximum vertical displacement was only .001". The beam direction displacements change sign at the 3 o'clock position, which indicates that ring is twisting. This twist is due to the load from the module not being applied at the shear center of the ring cross section. The mechanical analysis was followed by a thermal analysis of the rings. It was assumed that the temperature of the rings will be raised by 20° Fahrenheit. This temperature difference was chosen because it is the largest operating temperature range expected for the magnet. An FEA analysis, considering both the thermal and mechanical loading, was performed on the rings. The maximum stress was 12,175 psi. This stress occurs at the bottom support point on the rings. The majority of the ring has stresses of approximately 1,500 psi. The displacements are listed in Table 2 of the Appendix. Once again it can be seen that the ring is deflecting a significant amount (.023") in the beam direction. This gives a clear indication that the ring should be stiffened in order to eliminate twist, and that care should be taken to ensure that the loads are applied through the shear center of the cross section and not in line with the outside edge. Unlike the mechanical analysis in which the beam direction deflections changed signs, all of the beam direction deflections are in the positive direction. This is due to the flange in the inside diameter wanting to thermally expand outward. This expansion twists the web of the cross section and

displaces it in the positive beam direction. The vertical deflections were small and did not exceed .004".

Analysis of the Thinner 1-3/4" Ring

Next an analysis of the thin ring in the center of the module was performed. First, a mechanical analysis of the ring was performed considering only the mechanical loading of the ring. The maximum stress in the ring was 2,305 psi that occurred at the bottom support point of the ring. The majority of the ring has stresses of approximately 400 psi. Table 3 in the Appendix lists the displacements of the 1-3/4" thick ring at the $\eta = 0$ boundary. Once again the displacements in the vertical direction are small, approximately .001". However the displacements in the Z direction are as large as .009" and changes direction at the 3 o'clock position. This indicates that the ring is twisting due to it is not being loaded through the shear center of the cross section.

The thermal and mechanical analysis of the thinner 1-3/4" wide ring indicated that the maximum stress was 13,639 psi, and occurred at the points where the ring was supported. The average stress throughout the ring was approximately 2,300 psi. Table 4 in the Appendix lists the displacements of the ring. The maximum deflection in the beam direction was .012" and the maximum vertical deflection was only .003".

Additional Analysis of "C" Channel Cross Section

In order to compare different types of support an additional analysis was performed in which the thicker 2 3/4" thick ring was only supported at the top and bottom while keeping the mechanical loading the same.² The maximum stress in the ring increased to 9,932 psi that occurred at the top and bottom support points. The average stress throughout the remainder of the ring was approximately 1,000 psi. The maximum deflection in the beam direction was .035" and the maximum vertical deflection was .056". The deflections of the ring are listed in Table 5 in the Appendix.

Analysis of the Solid Cross Section Continuous Ring

Analysis of the 2-3/4" Thick Ring

An FEA analysis has been performed on the solid rectangular rings. Four separate analysis were performed: analysis of the thick 2 3/4" ring supported only at the top and bottom;³ analysis of the thick ring supported at 8 points;³ a thermal and mechanical analysis of the thick ring while supported at 8 points;³ and a thermal and mechanical analysis with a 50° Fahrenheit temperature rise. This temperature range was chosen because it was the largest temperature range expected between the non-operating temperature in the winter and the maximum summer operating temperature.

The first model analyzed was the thick 2 3/4" ring when it is supported only at the top and bottom. The maximum stress was 4,744 psi that was concentrated at the support at the top and bottom. The average stress throughout the ring was approximately 700 psi. This analysis was done to compare it with previous analyses made by T. Fornek. It should be noted that Tom's model did not model the cross section and therefore cannot predict the concentrated stresses at the support. In addition it could not analyze the stresses in the ring due to the twisting of the ring that occurs because it is not loaded through the shear center. The maximum beam direction deflection was .009" and the maximum vertical deflection was .029". The deflections of the ring are listed in Table 6 of the Appendix.

The deflections in the vertical direction are quite large. The most disturbing deflections however are those in the Z direction. The inner radius of the ring moves cyclically inward and then outward which is an indication of buckling.

The thick ring was then analyzed when it was supported at 8 points. The maximum stress was 1,587 psi and occurs at the support points. The average stress throughout the ring was approximately 300 psi. The maximum beam deflection was only .002" and the maximum vertical deflection was nearly zero at .0007". The deflections are listed in Table 7 of the Appendix.

The deflections are substantially smaller when the ring is supported at 8 points. The deflections in the Z directions are much smaller and only change sign once. The Z direction deflections in this case are due entirely to the load being

applied off center. The change in sign of the Z deflections is caused simply by the change in direction of the applied load at different positions along the ring.

The next analysis performed on the thick ring was a thermal analysis in which the temperature rise was 20° Fahrenheit. The maximum stress was 12,622 psi that occurs at the support at the bottom. The average stress throughout the ring was approximately 2,300 psi. The maximum deflection in the beam direction was .003" and the maximum vertical deflection was .004". The deflections of the ring are listed in Table 8 of the Appendix.

As a check of the FEA model, the element mesh of the thick ring was doubled. The same thermal and mechanical analysis was then performed. The deflections of the ring were identical, however the concentrated stresses at the bottom support increased to 15,000 psi. This would indicate that the basic model is accurate, however the concentrated stresses that occur at the support points are difficult to predict because of the difficulty in accurately modeling the connection.

The final analysis of the thick solid cross section is a thermal analysis in which the temperature of the rings is raised 50° Fahrenheit. The maximum stress in the ring increased significantly to 29,075 psi that occurred at the bottom support point. The maximum deflection in the beam direction was .004" and the maximum deflection in the vertical direction was .008" which are still insignificant. The deflections are listed in Table 9 in the Appendix.

Analysis of Thin 1-3/4" Ring

A thermal analysis was performed on the thinner center rings.³ A 20° Fahrenheit temperature rise was assumed and the ring was supported at 8 points. The maximum stress was 13,399 psi at the bottom support. The maximum deflection in the beam direction was .006" and the maximum deflection in the vertical direction was only .003". The deflections of the ring are listed in Table 10 in the Appendix.

An additional thermal analysis was performed in which the temperature of the ring was raised 50° Fahrenheit. The maximum stress was 30,152 psi that occurred at the bottom support. The average stress throughout the ring was approximately 6,000 psi. The maximum deflection in the beam direction was .006"

and the maximum deflection in the vertical direction was .008". The deflection of the ring are listed in Table 11 in the Appendix.

The deflections of the ring when the temperature is raised 20° and 50° are very similar because the ring is supported the same was in both models and is restrained from moving in the radial direction.

Conclusion

It is clear that the initial design of a continuous ring with a "C" cross section cannot meet the stress and deflection requirements of the EM calorimeter. The continuous ring with a solid cross section is much stiffer, however the stresses from thermal loading are still very high. There are three ways to eliminate the high thermal stresses: segment the ring; allow the continuous rings to expand radially; and reduce the operating temperature range of the coils.

References

- 1) "FEA Calculations of STAR Support Rings", V. Guarino in memo to H. Spinka et al., 07 December 1993.
- 2) "FEA Calculations of STAR Support Rings, V. Guarino in memo to H. Spinka et al., 16 December 1993.
- 3) "FEA Analysis of Solid Rings, V. Guarino in memo to D. Underwood et al., 20 December 1993.

APPENDIX

Table 1

"C" Channel Cross Section Mechanical Analysis
Displacement of 2-3/4" Wide Ring -- Supported at 8 Points

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.007	-.0008
2	.007	-.0009
3	.006	-.001
4	.006	-.001
5	.006	-.001
6	.006	-.0007
7	.006	-.0007
8	.005	-.0007
9	.005	-.0005
10	.005	-.0003
11	.004	-.0003
12	.003	-.0002
13	.002	-.0003
14	.001	-.0001
15	.0006	0
16	-.0005	0
17	-.001	-.0001
18	-.002	-.0003
19	-.002	-.0002
20	-.003	-.0003
21	-.004	-.0002
22	-.005	-.0003
23	-.005	-.0005
24	-.006	-.0006
25	-.006	-.0007
26	-.006	-.0009
27	-.006	-.001
28	-.006	-.001
29	-.006	-.0009
30	-.006	-.0008

Table 2**"C" Channel Cross Section Thermal and Mechanical Analysis**

*Displacement of 2-3/4" Wide Ring -- Supported at 8 Points
20° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.0148	-.004
2	.0182	-.003
3	.023	-.001
4	.0229	-.0008
5	.0187	-.002
6	.018	-.0025
7	.022	-.001
8	.021	-.0002
9	.017	-.001
10	.016	-.001
11	.020	-.0008
12	.019	.0003
13	.014	0
14	.013	-.001
15	.016	-.0005
16	.015	.0005
17	.010	.0008
18	.010	-.0006
19	.013	-.0007
20	.013	.0001
21	.007	.001
22	.006	.0001
23	.010	-.001
24	.009	-.0003
25	.005	.001
26	.005	.0001
27	.009	-.001
28	.009	-.001
29	.004	.001
30	.001	.002

Table 3**"C" Channel Cross Section Mechanical Analysis***Displacement of 1-3/4" Wide Ring -- Supported at 8 Points*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.009	-.001
2	.009	-.001
3	.009	-.001
4	.009	-.001
5	.009	-.001
6	.009	-.0009
7	.008	-.0009
8	.007	-.0008
9	.006	-.0007
10	.006	-.0005
11	.005	-.0005
12	.004	-.0004
13	.003	-.0001
14	.002	-.0002
15	.0007	-.0001
16	-.0005	-.0004
17	-.0001	-.0002
18	-.002	-.0001
19	-.004	-.0002
20	-.009	-.0003
21	-.009	-.0004
22	-.009	-.0006
23	-.009	-.0008
24	-.009	-.0009
25	-.009	-.0009
26	-.009	-.001
27	-.009	-.001
28	-.009	-.001
29	-.009	-.001
30	-.009	-.0009

Table 4**"C" Channel Cross Section Thermal and Mechanical Analysis**

*Displacement of 1-3/4" Wide Ring -- Supported at 8 Points
20° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.006	-.003
2	.008	-.002
3	.011	-.0009
4	.011	-.0005
5	.007	-.001
6	.007	-.002
7	.009	-.0007
8	.008	0
9	.004	-.0007
10	.004	-.001
11	.006	-.0006
12	.005	-.0002
13	.001	-.0002
14	.0002	-.001
15	.001	-.0005
16	.0004	.0003
17	-.003	.0005
18	-.005	-.0005
19	-.003	-.0008
20	-.004	-.0002
21	-.009	-.0006
22	-.009	-.0005
23	-.007	-.001
24	-.008	-.001
25	-.011	-.0001
26	-.011	-.0007
27	-.007	-.001
28	-.007	-.001
29	-.010	-.0003
30	-.012	-.0001

Table 5**Mechanical Loading of "C" Section Ring***Displacement of 2-3/4" Wide Ring -- Supported at 2 Points*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.027	-.004
2	.022	-.008
3	.015	-.016
4	.007	-.024
5	.0007	-.032
6	-.005	-.040
7	-.009	-.046
8	-.012	-.051
9	-.012	-.054
10	-.011	-.056
11	-.009	-.056
12	-.005	-.056
13	.0002	-.055
14	.006	-.054
15	.013	-.054
16	.019	-.054
17	.025	-.054
18	.030	-.055
19	.034	-.055
20	.035	-.056
21	.034	-.055
22	.031	-.053
23	.026	-.050
24	.020	-.045
25	.013	-.039
26	.004	-.031
27	-.004	-.023
28	-.013	-.015
29	-.020	-.008
30	-.026	-.003

Table 6**Solid Cross Section***Deflections of the Thick 2-3/4" Wide Ring -- Supported at Top and Bottom*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.007	-.001
2	.006	-.004
3	.004	-.007
4	.001	-.012
5	-.0008	-.016
6	-.003	-.020
7	-.005	-.024
8	-.007	-.026
9	-.009	-.028
10	-.009	-.029
11	-.009	-.029
12	-.008	-.029
13	-.007	-.029
14	-.005	-.029
15	-.003	-.028
16	-.001	-.028
17	0	-.028
18	.001	-.029
19	.003	-.029
20	.004	-.029
21	.005	-.029
22	.005	-.028
23	.004	-.026
24	.003	-.024
25	.001	-.020
26	-.0004	-.016
27	-.002	-.012
28	-.004	-.008
29	-.006	-.004
30	-.007	-.002

Table 7**Solid Cross Section***Deflections of the Thick 2-3/4" Wide Ring -- Supported at 8 Points*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.002	-.0005
2	.002	-.0005
3	.002	-.0007
4	.002	-.0007
5	.002	-.0007
6	.002	-.0006
7	.002	-.0005
8	.002	-.0005
9	.002	-.0004
10	.002	-.0003
11	.001	-.0002
12	.001	-.0002
13	.001	0
14	.0009	-.0001
15	.0006	-.0001
16	.0003	0
17	-.0001	0
18	-0.006	0
19	-.001	-.0001
20	-.001	-.0001
21	-.001	-.0002
22	-.001	-.0002
23	-.002	-.0003
24	-.002	-.0004
25	-.002	-.0005
26	-.002	-.0005
27	-.002	-.0006
28	-.002	-.0007
29	-.002	-.0007
30	-.002	-.0005

Table 8**Solid Cross Section**

*Deflections of the Thick 2-3/4" Wide Ring -- Supported at 8 Points
20° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.001	-.004
2	.002	-.002
3	.002	-.0008
4	.002	-.0003
5	.002	-.001
6	.002	-.002
7	.002	-.0006
8	.001	0
9	.001	-.0007
10	.001	-.001
11	.001	-.0006
12	.0009	-.0004
13	.0005	.0001
14	.0002	-.0009
15	-.0001	-.0005
16	-.0006	.0005
17	-.001	.0008
18	-.001	-.0003
19	-.001	-.0006
20	-.002	.0001
21	-.002	.001
22	-.002	0
23	-.002	-.0009
24	-.003	-.0003
25	-.003	.0009
26	-.003	.0002
27	-.003	-.001
28	-.003	-.0007
29	-.003	.001
30	-.003	.002

Table 9**Solid Cross Section**

*Deflections of the Thick 2-3/4" Wide Ring -- Supported at 8 Points
50° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.002	-.008
2	.002	-.005
3	.001	-.0008
4	.001	.0002
5	.002	-.002
6	.001	-.004
7	.001	-.001
8	.001	.0006
9	.001	-.001
10	.0009	-.003
11	.0005	-.001
12	.0002	.001
13	0	.0004
14	-.0003	-.002
15	-.0008	-.001
16	-.001	.001
17	-.001	.002
18	-.002	-.0007
19	-.002	-.001
20	-.003	.0007
21	-.003	.002
22	-.003	.0006
23	-.003	-.001
24	-.004	0
25	-.003	.003
26	-.004	.001
27	-.004	-.001
28	-.004	-.0007
29	-.004	.004
30	-.004	.007

Table 10**Solid Cross Section Thermal and Mechanical Analysis**

*Deflections of the Thick 1-3/4" Ring -- Supported at 8 Points
20° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.005	-.003
2	.005	-.002
3	.005	-.001
4	.005	-.0008
5	.005	-.001
6	.005	-.002
7	.005	-.001
8	.004	.0004
9	.004	-.001
10	.003	-.001
11	.002	-.0009
12	.002	0
13	.001	-.0003
14	.0008	-.001
15	0	-.0009
16	-.0006	0
17	-.001	.0003
18	-.002	-.0008
19	-.002	-.001
20	-.003	-.0002
21	-.004	.0006
22	-.004	-.0004
23	-.005	-.001
24	-.005	-.0007
25	-.006	.0008
26	-.006	-.0001
27	-.006	-.001
28	-.006	-.001
29	-.006	.0009
30	-.006	.002

Table 11**Solid Cross Section Thermal and Mechanical Analysis**

*Deflections of the Thick 1-3/4" Ring -- Supported at 8 Points
50° Temperature Rise*

Module #	Z Displacement (in.)	Vertical Displacement (in.)
1	.005	-.008
2	.005	-.005
3	.005	-.001
4	.005	-.0001
5	.005	-.003
6	.005	-.004
7	.004	-.001
8	.004	.0002
9	.003	-.001
10	.003	-.003
11	.002	-.001
12	.001	.0006
13	.001	0
14	.0004	-.002
15	-.0004	-.003
16	-.001	.0007
17	-.001	.001
18	-.002	-.001
19	-.003	-.001
20	-.003	.0003
21	-.004	.002
22	-.005	.0001
23	-.005	-.002
24	-.006	-.0004
25	-.006	.002
26	-.006	.001
27	-.006	.002
28	-.006	-.001
29	-.006	.003
30	-.006	.006

FIG-1
C CROSS-SECTION

FIG-2
SOLID CROSS-SECTION

Figure 3

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