OAK RIDGE National Laboratory

Preliminary Tube Hydrogen Vessel Stress Analysis

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8/17/2022

U.S. DEPARTMENT OF ENERGY

Tube Moderator Stress Analysis Overview

- Hydrogen vessels shall be designed to the intent of the ASME BPVC
- Analysis guided by 2021 ASME BPVC Section VIII D2
  - Elastic Analysis Approach
  - Allowables from code case 2478-1
    - Al 6061-T6 Hand Forging up to 4" thickness – S = 85 MPa, S_{M+B} = 127 MPa
    - Al 6061-T6 Welded – S = 55 MPa, S_{M+B} = 83 MPa
- Only 19 bar Internal Pressure considered
  - Negligible thermal stress due to CTE ~ 0 at 20 K operating temperature
  - Negligible static head and fluid momentum effects due to low density operating fluid
  - Negligible deadweight load – vessel mass is 0.26 kg
  - Non-existent snow and wind loading
  - Earthquake loads will need to be considered in final design

Material Properties

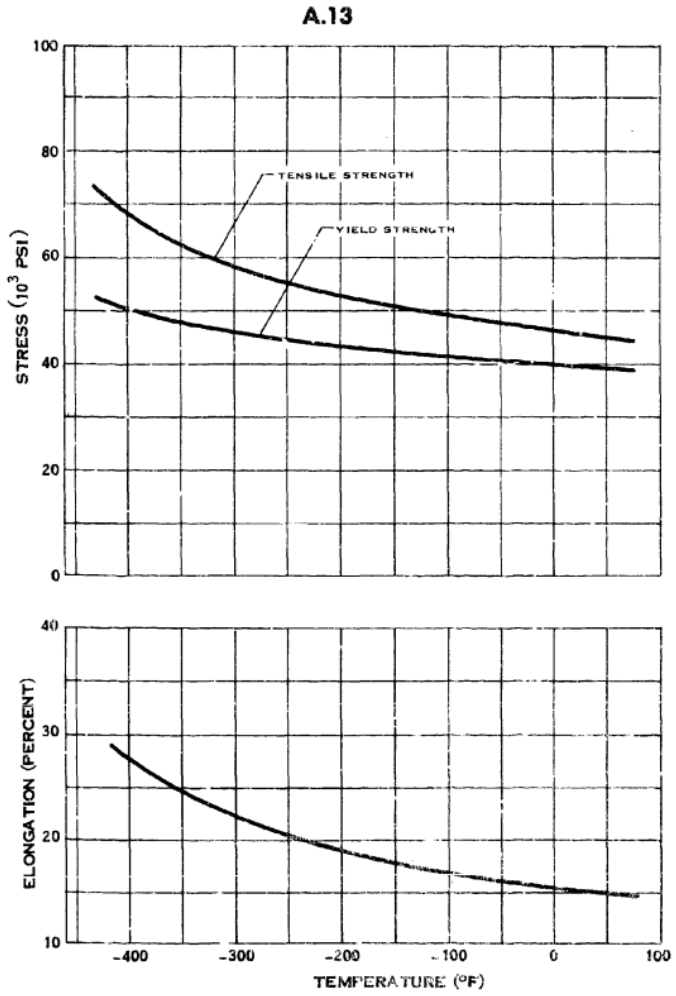
- **Aluminum 6061-T6 properties**

Modulus of Elasticity (GPa)	68.9
Poisson's Ratio	0.33
(100° F) Sm (MPa)	85
Sm Weld (MPa)	55

ASME BPVC Section8 Division 2 Allowable equivalent stress values
Code case 2478-1

	Sm Membrane	**Sm Membrane+ Bending (1.5x)**	**Sm Membrane+ Bending + Secondary (3x)**
Non-Weld Regions (MPa)	85 MPa	127 MPa	254 MPa
Weld regions	55 MPa	83 MPa	165 MPa

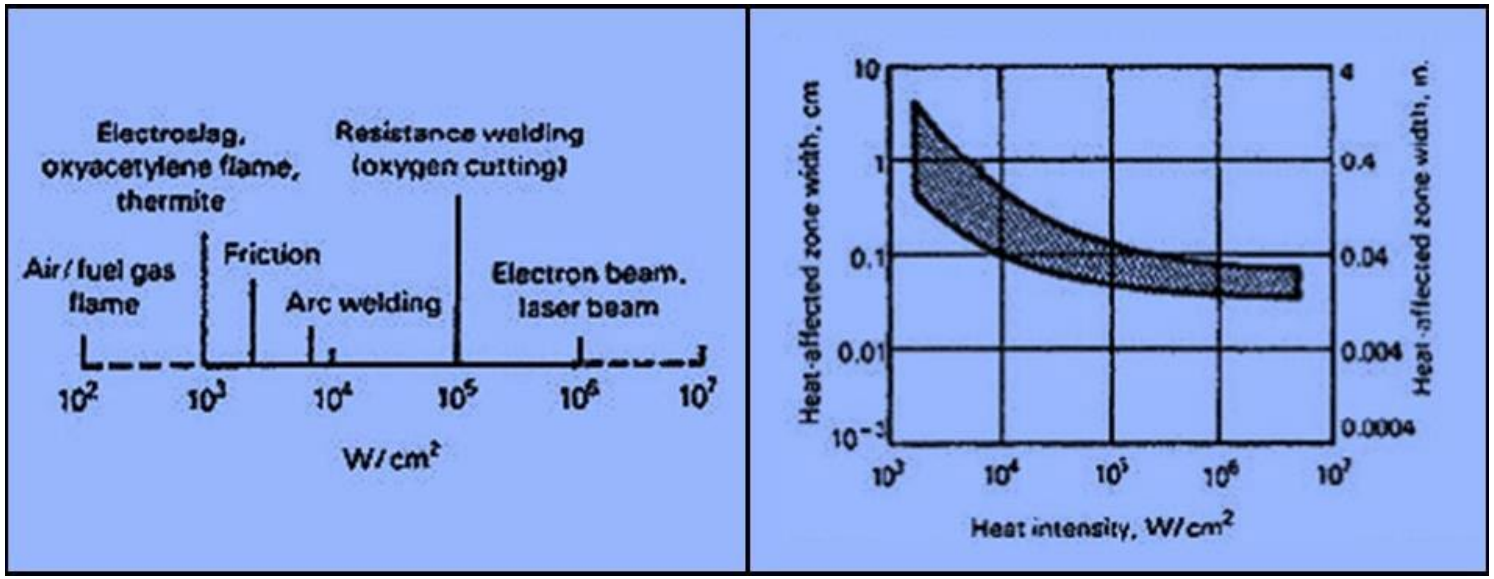
Note: 6061-T6 is stronger and more ductile at 20 K (-423°F) operating temperature, but the BPVC does not allow taking credit for this increase



Cryogenic Materials Data Handbook, AFML-TDR-64-280, Air Force Materials Laboratory, 1970

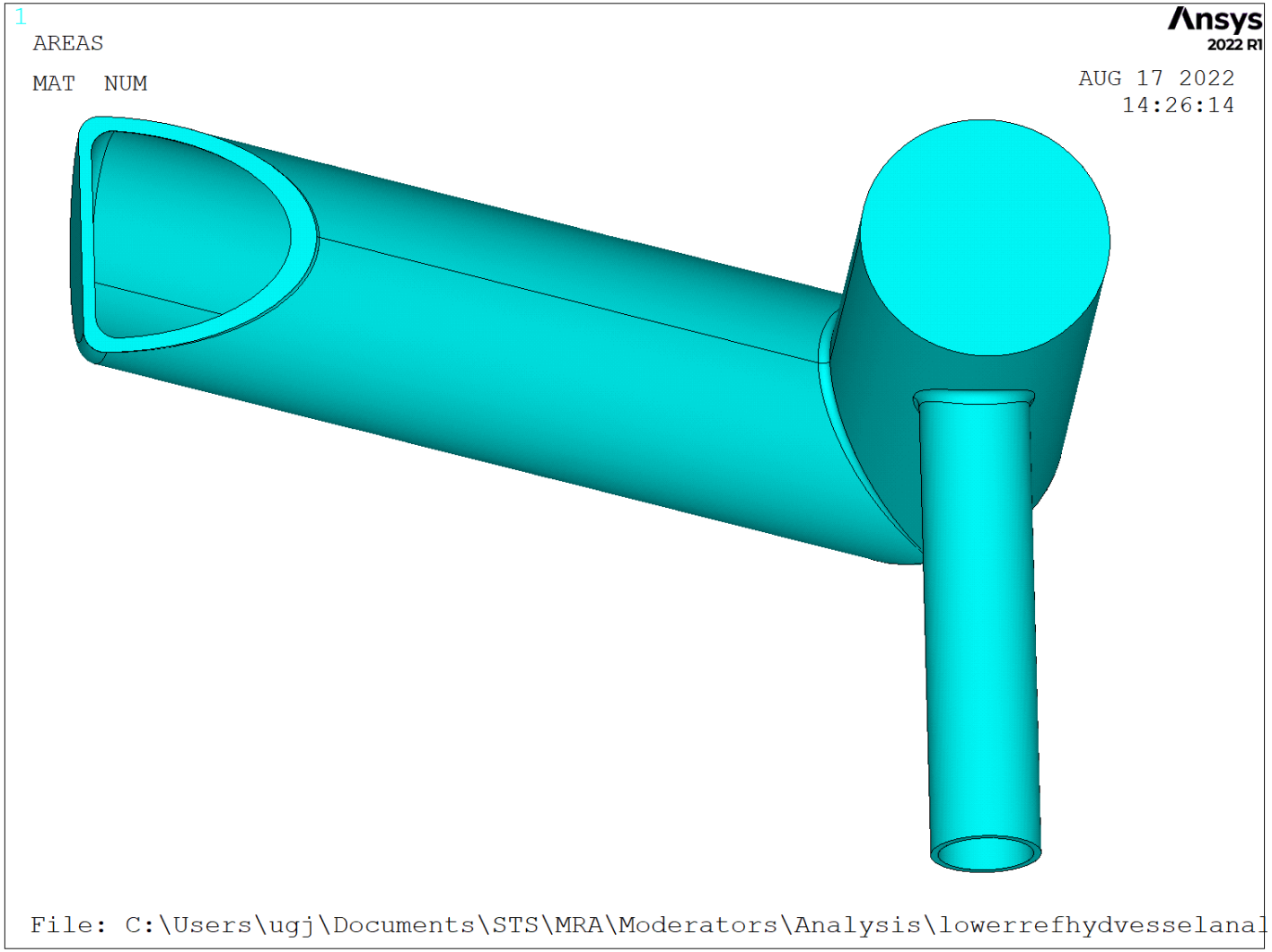
Weld Heat Affected Zone Width

- Weld width of cosmetic pass of up to 5mm from cylinder moderator prototypes
- Heat affected zone width of 1mm from the chart below
- Total weld heat affected zone width of 6 mm, or 3mm from the centerline of the weld



Nominal Tube Moderator Geometry

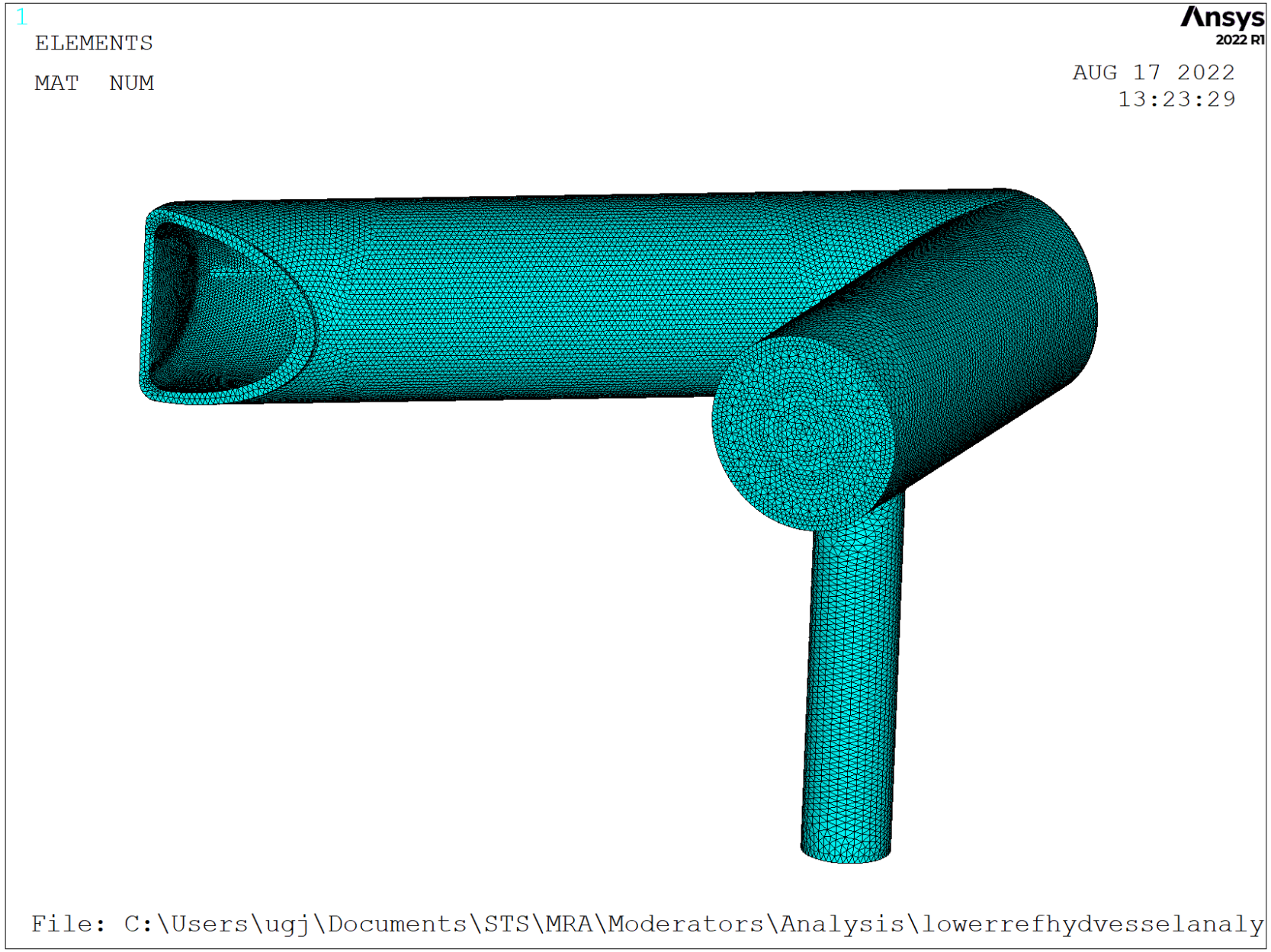
- Tube moderator geometry from preliminary optimization
  - 170mm tube length
  - 2mm wall thickness
  - 1.7mm window thickness
- ½ symmetry model with symmetry boundary condition on the symmetry planes



Ansys File Name: lowerhydvesselanalysis-r5.db
Parasolid File Name: lowerrefhydvesselanalysis-r5c.x_t
Creo File Name: lowerrefhydvesselanalysis-r5.prt

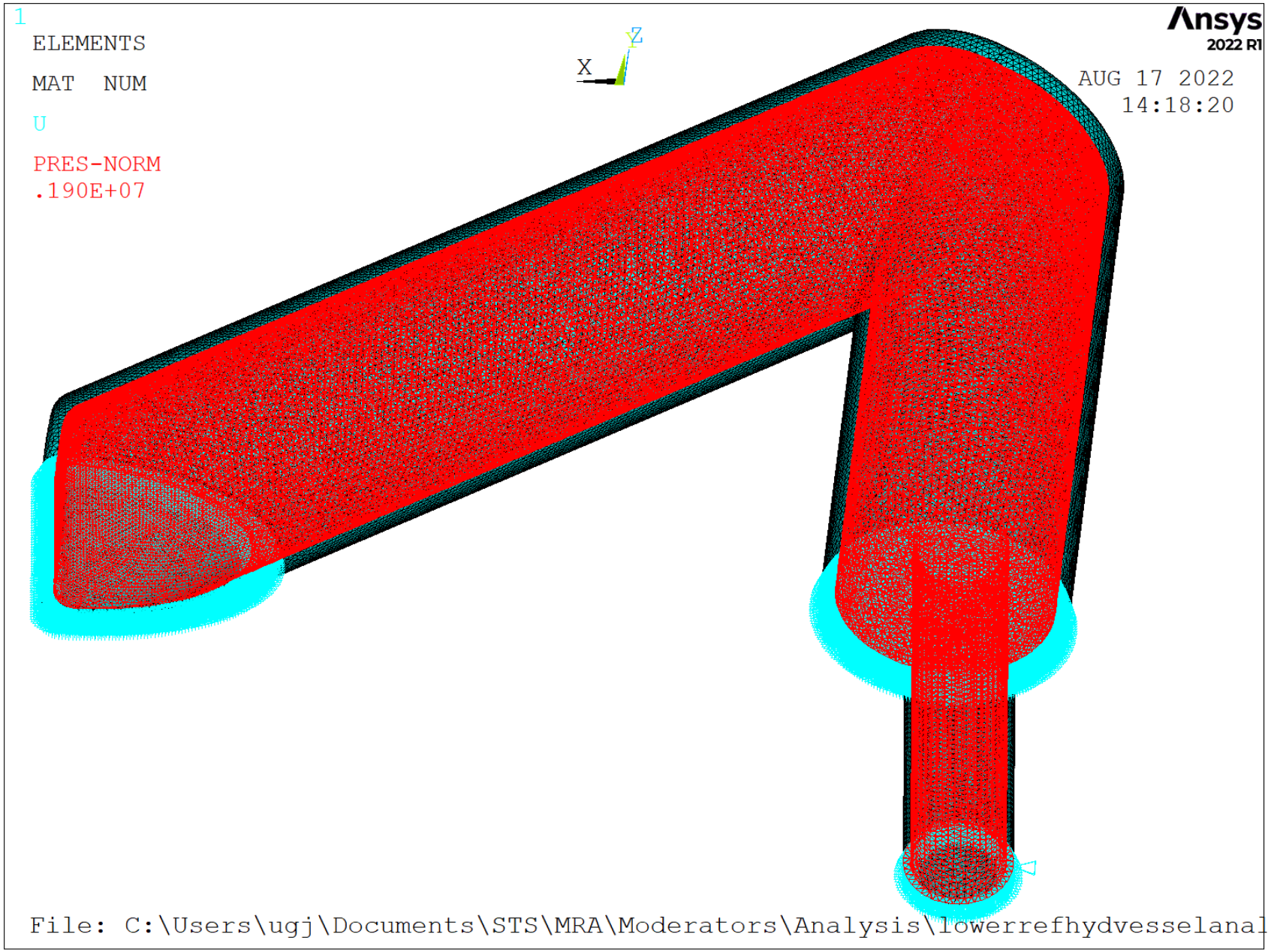
Mesh

- 10 node tet elements
- 451888 elements
- 739569 nodes
- Mesh refined in high stress corners



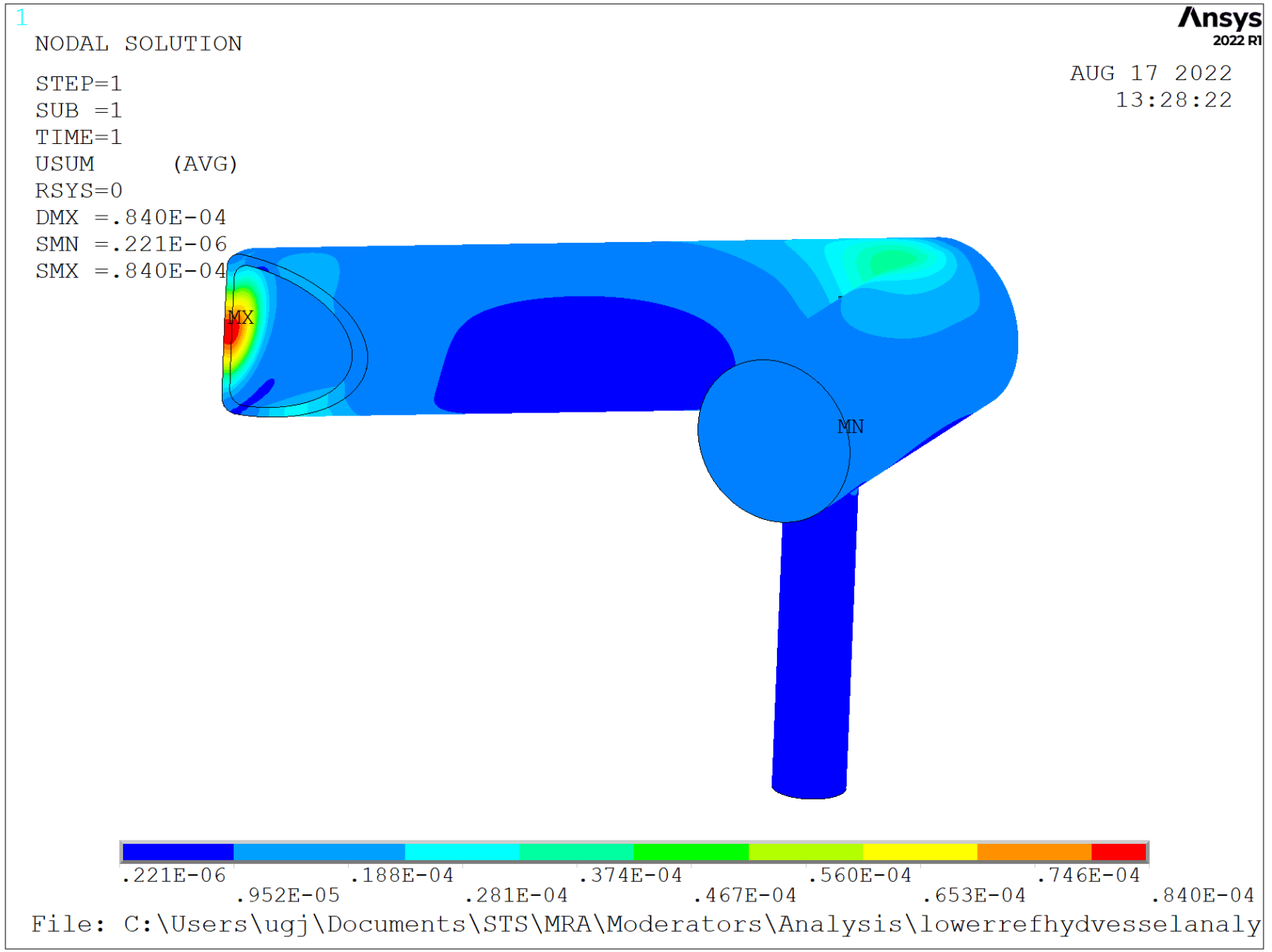
Loads

- 19 bar internal pressure
- Symmetry conditions on symmetry plane
- Fixed vertically at hydrogen pipe end



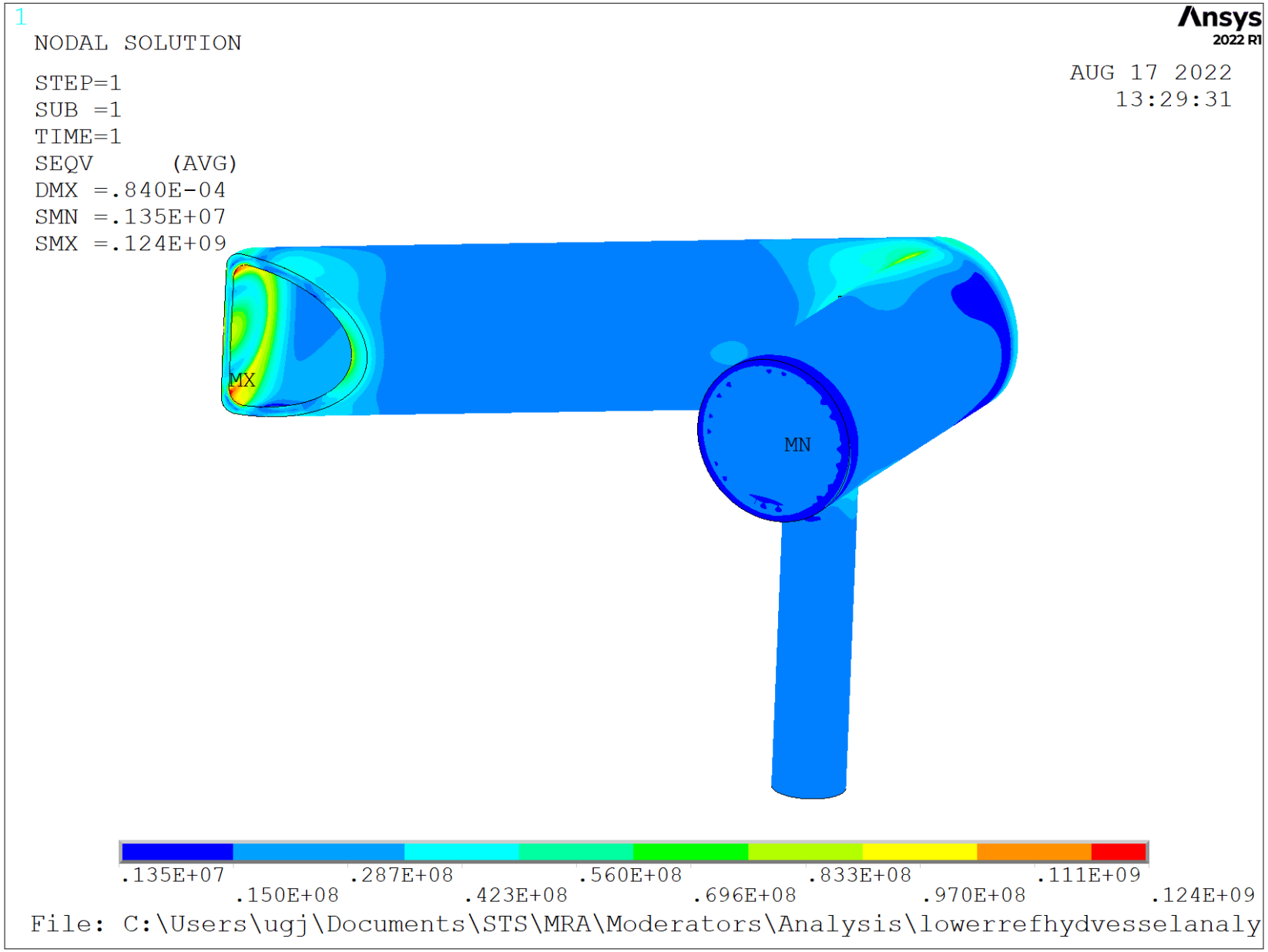
Displacement Contour Plot

- Maximum displacement is 0.084mm
- Tubes make for extremely stiff structure with very little displacement from 19 bar loads



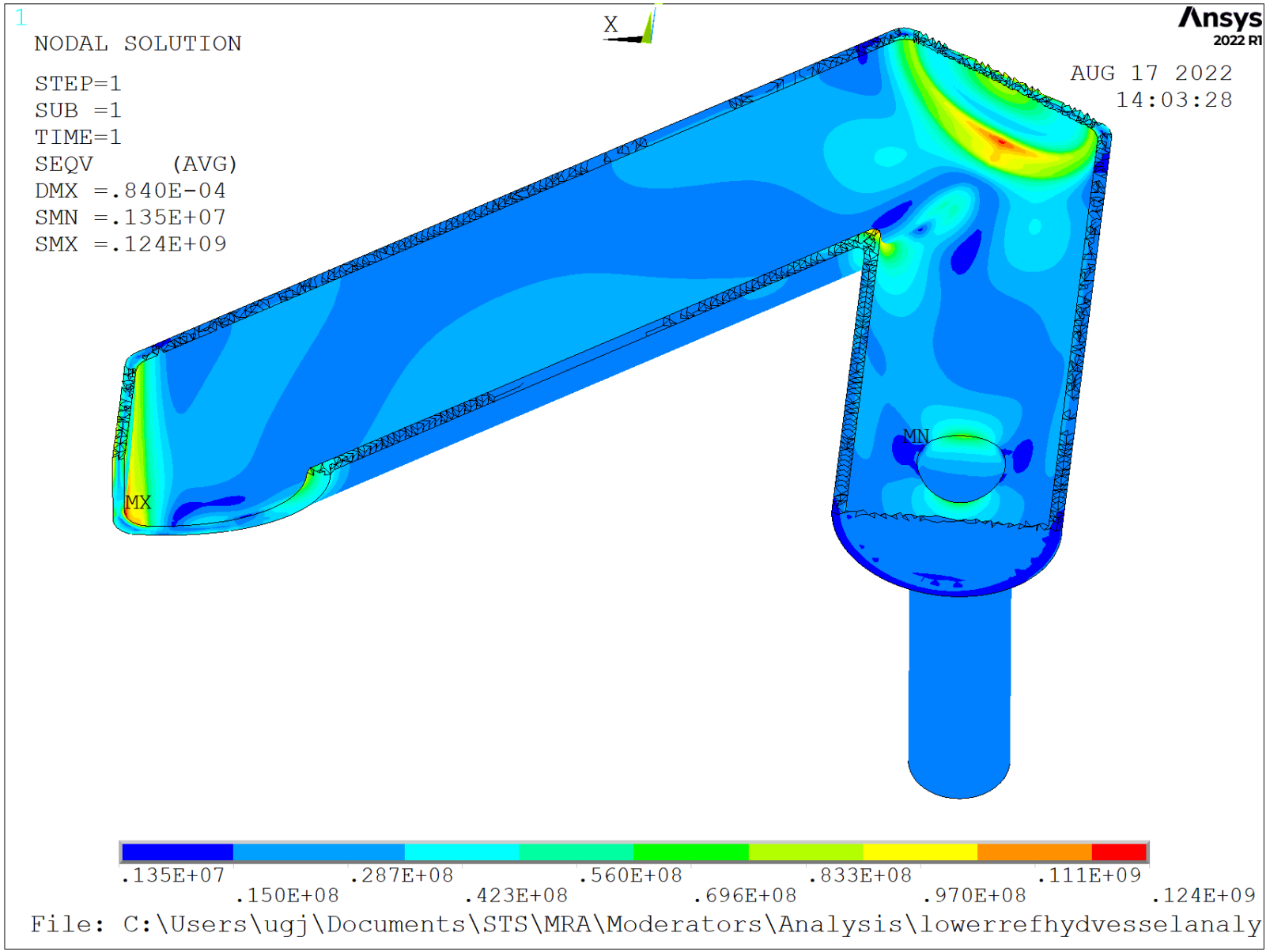
Von Mises Stress Contour Plot

- Maximum Von Mises Stress of 124 MPa on radius of window joining the two shorter tubes
- All locations 127 MPa or lower, which meets the M+B allowable



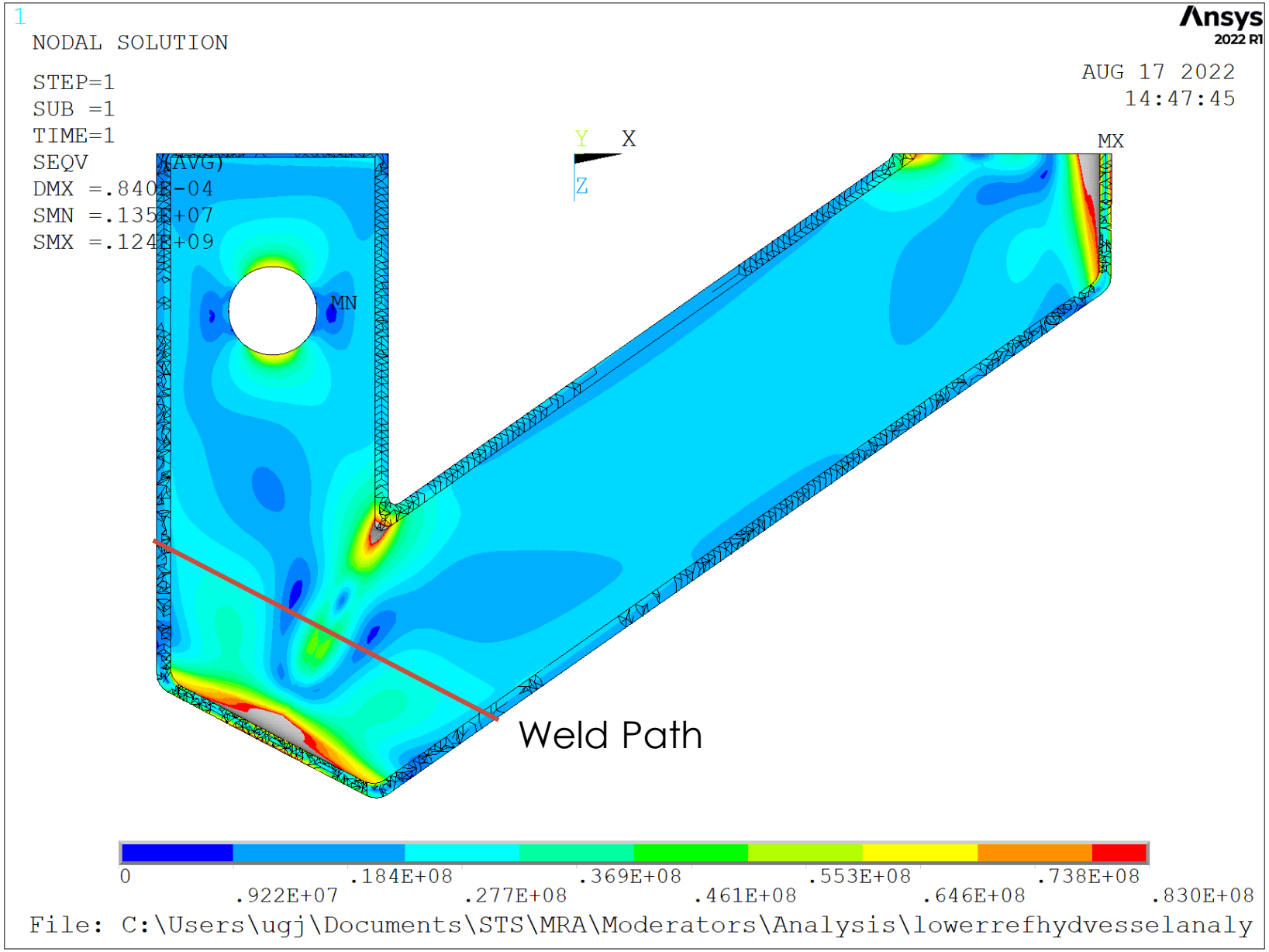
Von Mises Stress Contour Plot

- Cross section cut along moderator horizontal center
- Asymmetry caused by hydrogen pipes seems to have little effect on high stress regions
- Hydrogen pipe connection shows low stresses



Von Mises Stress Contour Plot - Welds

- Stresses much below the 83 MPa weld M+B allowable in region of the weld
- Weld is ~12 mm from the high stress zones in either direction



Results Summary

	Maximum Von Mises Stress (MPa)	Minimum Distance Overstress to Weld (mm)
Allowable	127	3
Actual	124	12

Conclusions

- The preliminary tube hydrogen vessel design meets the intent of the ASME BPVC
- Stresses in bulk and weld affected zones meet allowable stress requirements
- Additional loads to consider during final design – but not expected to affect vessel design
  - Internal vacuum condition
  - Seismic loads