Design of Octo-Strain Device for Sheet Metal Testing using Neutron Diffraction

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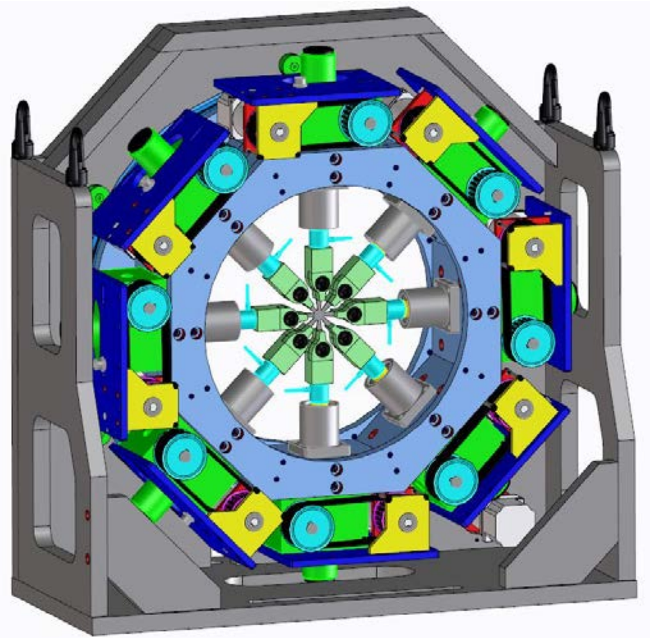
CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NSF NIST



Motivation

- Automotive lightweighting Research
  - Meet demand to develop automobiles with increased fuel efficiency
  - Improvements in crash test ratings
  - Create material models that accurately represent mechanical properties of material
    - Saves cost by producing correct metal forming dies that require zero rework because of incorrect modeling

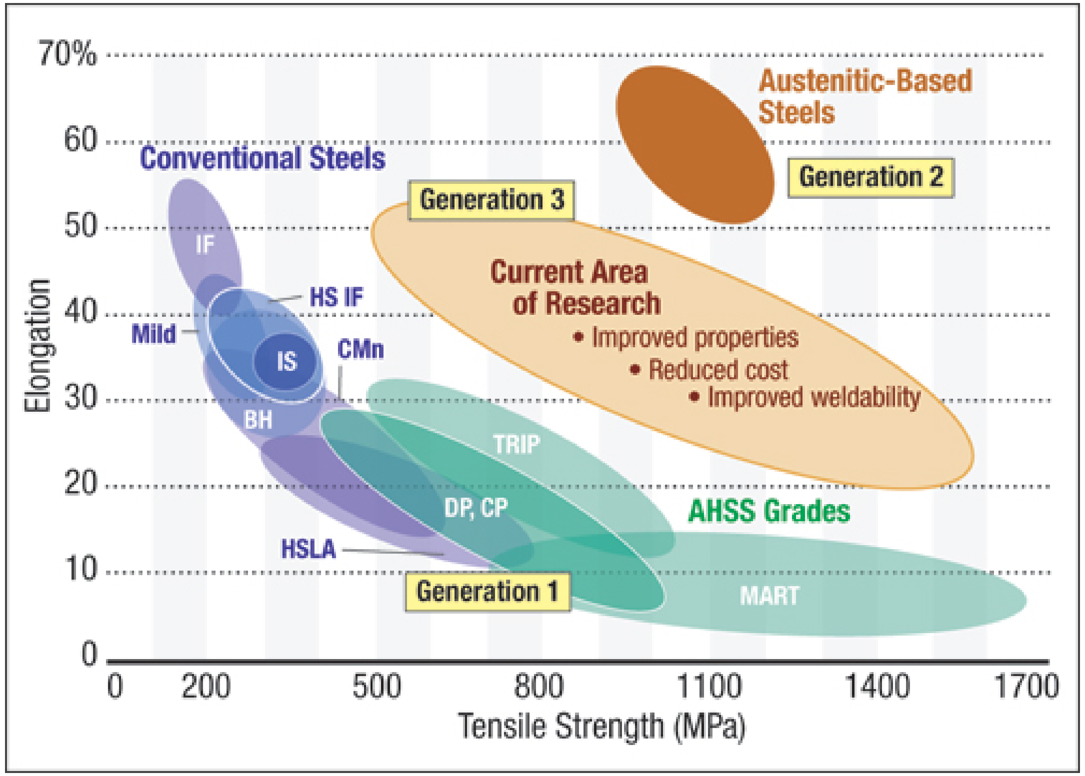


Figure 1: Chart displaying steel development [1]

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Motivation- Continued

- Traditional uniaxial testing is not an accurate enough measurement for the prediction of complex multiaxial deformation

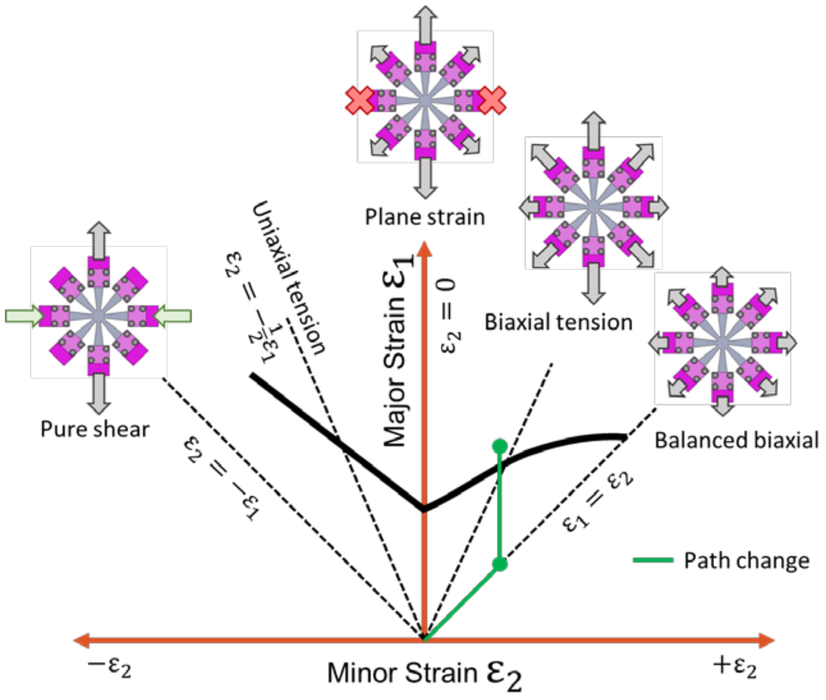


Figure 2: Various Strain Paths for Octo-Strain Device

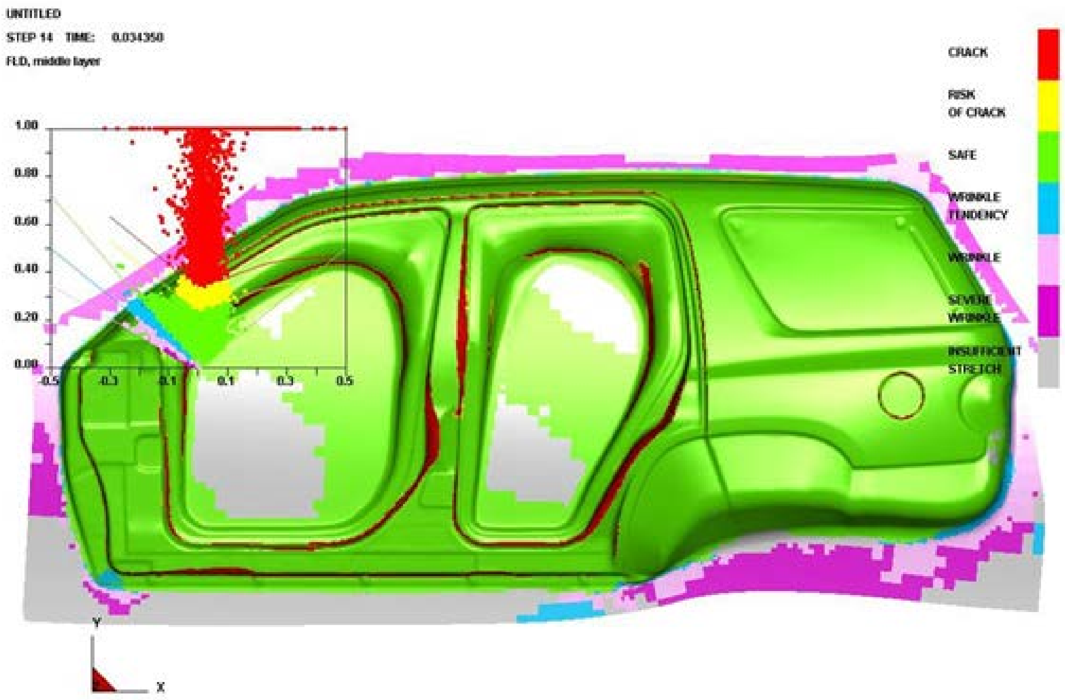


Figure 3: Strain Paths when Forming Automotive Parts

Introduction- What is Octo-Strain?

- A device used for multi-axial sheet metal testing
- Designed for specialized test specimens with eight arms
- Eight linear actuators apply tensile or compressive forces to the test specimen

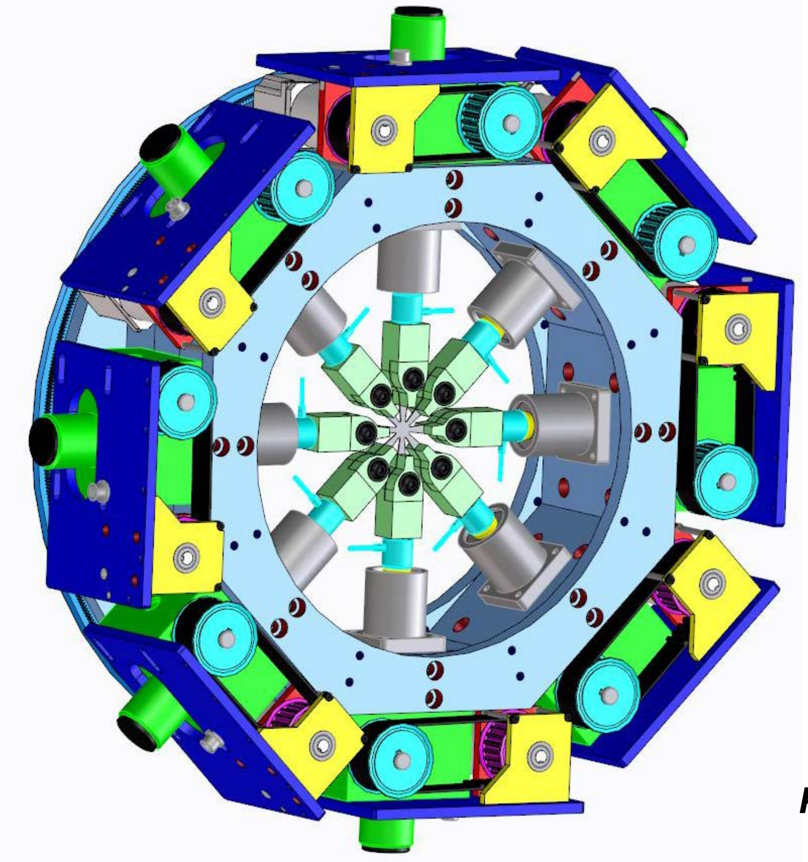


Figure 4: Assembled Octo-Strain Ring

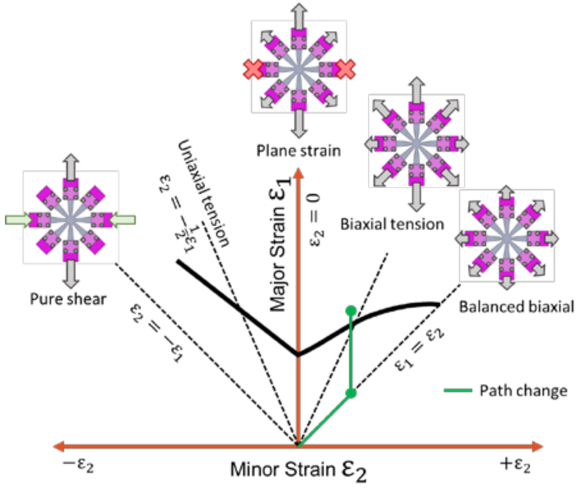
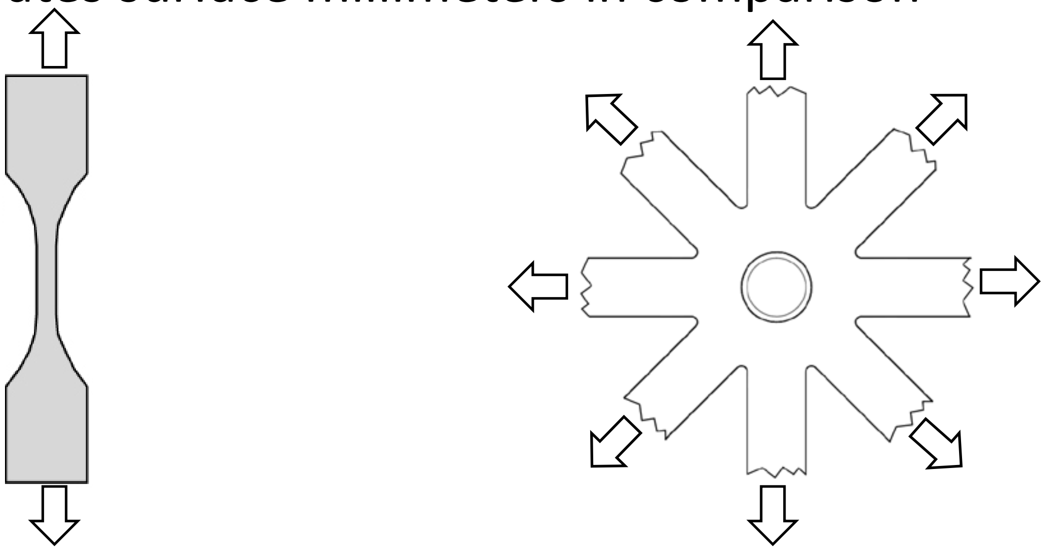


Figure 5: Strain Space for Octo-Strain [2]

Introduction- Why use Neutron Diffraction?

- Unlike traditional tensile testing, cross-sectional area is difficult to calculate for complex geometries
- Neutrons are non-destructive with high penetration depth (cm)
  - X-ray Diffraction penetrates surface millimeters in comparison

$$\sigma = \frac{F}{A} \checkmark$$

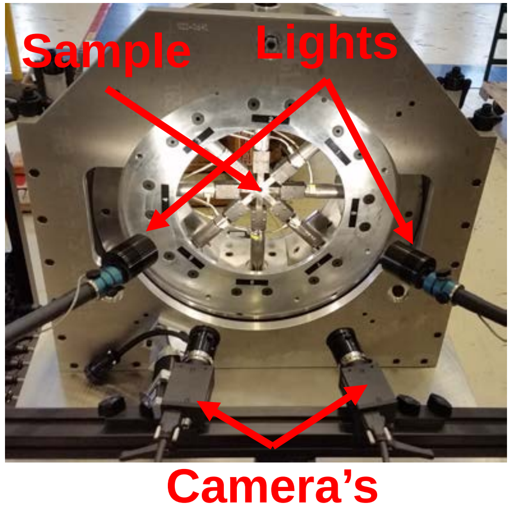


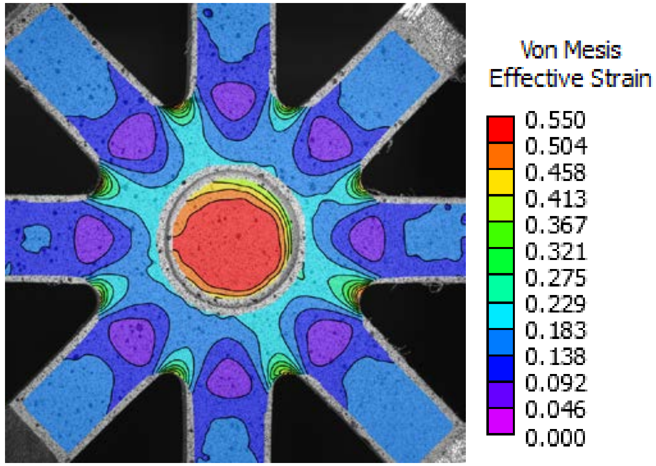
$$\sigma = \frac{F}{A}$$

Cross-sectional Area and forces that act on the gauge area is unknown

Figure 6: Comparing traditional tensile test specimen to Octo-Strain test specimen

Introduction- Stress-Strain Relationship





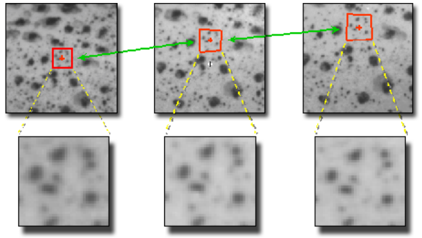
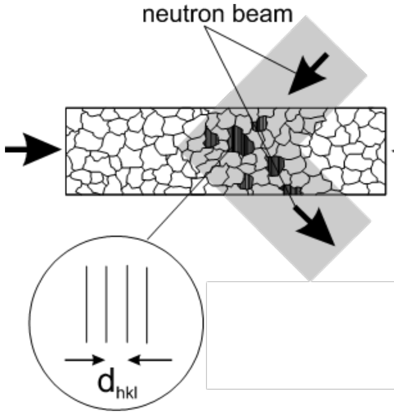


Figure 7: Speckle Pattern Used for Strain [3]

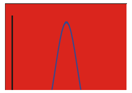
$$\varepsilon = \frac{\Delta L}{L}$$

Figure 8: Finding Strain using Digital Image Correlation



Bragg's Law

$$\lambda = 2d_{hkl}\sin\theta$$



Lattice Strain

$$\varepsilon = \frac{d - d_0}{d_0}$$

Hooke's Law

$$\sigma_x = \frac{E}{(1+\nu)(1-2\nu)}\left[(1-\nu)\varepsilon_x + \nu\left(\varepsilon_y + \varepsilon_z\right)\right]$$

$$\sigma_y = \frac{E}{(1+\nu)(1-2\nu)}\left[(1-\nu)\varepsilon_y + \nu\left(\varepsilon_x + \varepsilon_z\right)\right]$$

$$\sigma_z = \frac{E}{(1+\nu)(1-2\nu)}\left[(1-\nu)\varepsilon_z + \nu\left(\varepsilon_x + \varepsilon_y\right)\right]$$

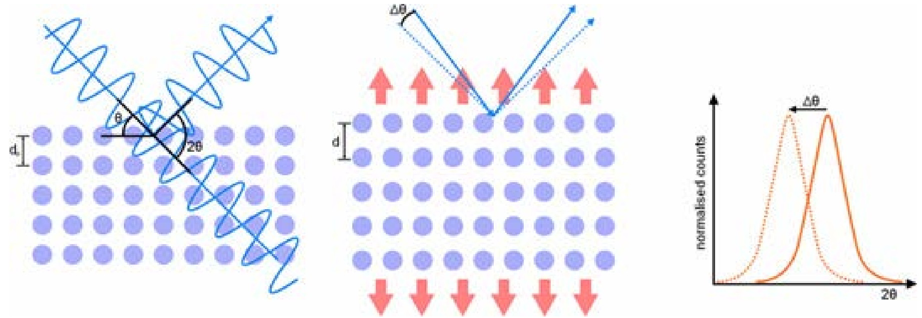


Figure 9: Finding Stress using Neutron Diffraction

Introduction- Stress-Strain Relationship

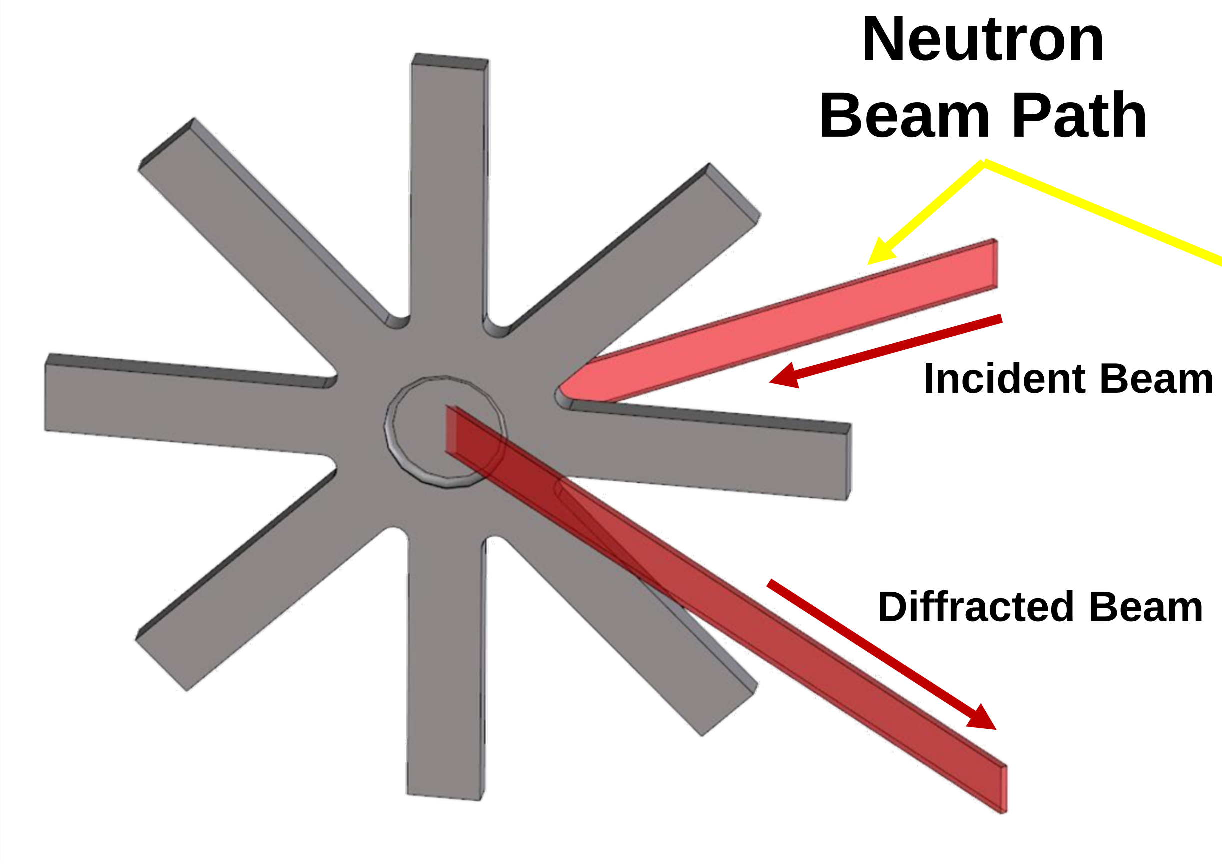


Figure 10: CAD model of Octo-Strain Test Specimen

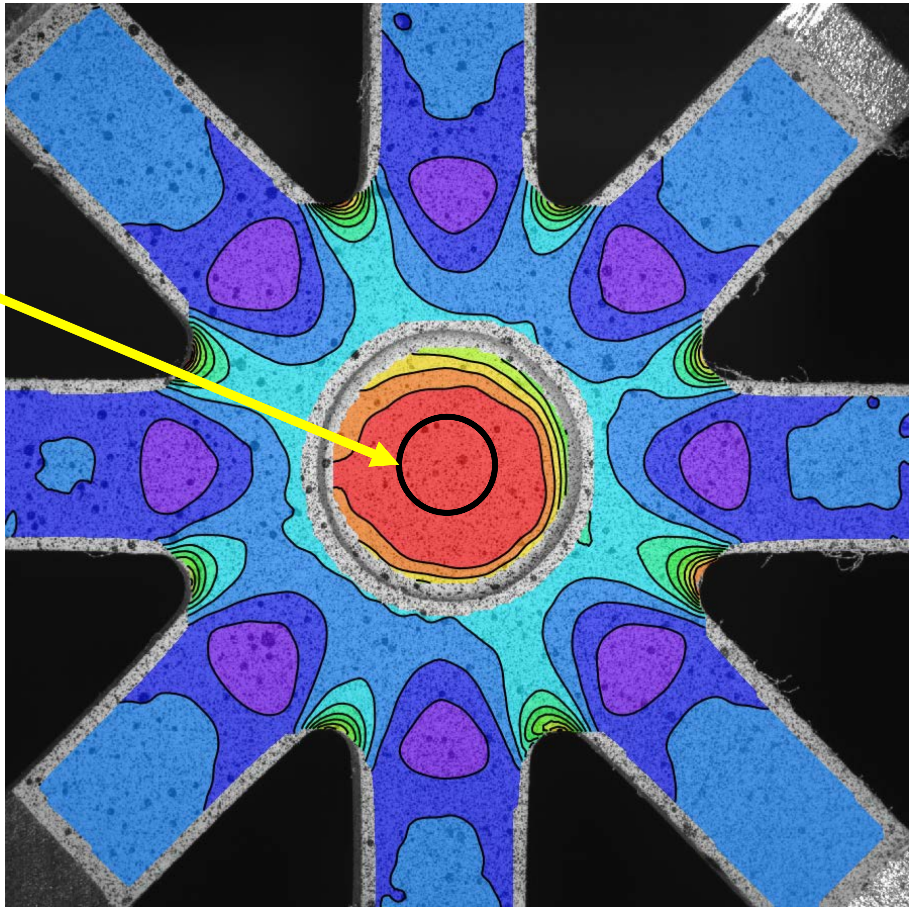


Figure 11: Neutron Beam Path Location

Introduction- Benefits of test specimen geometry

- Increased failure strain by over 2x
- Increased strain homogeneity within gauge area
- Early failure due to sample geometry of Cruciform

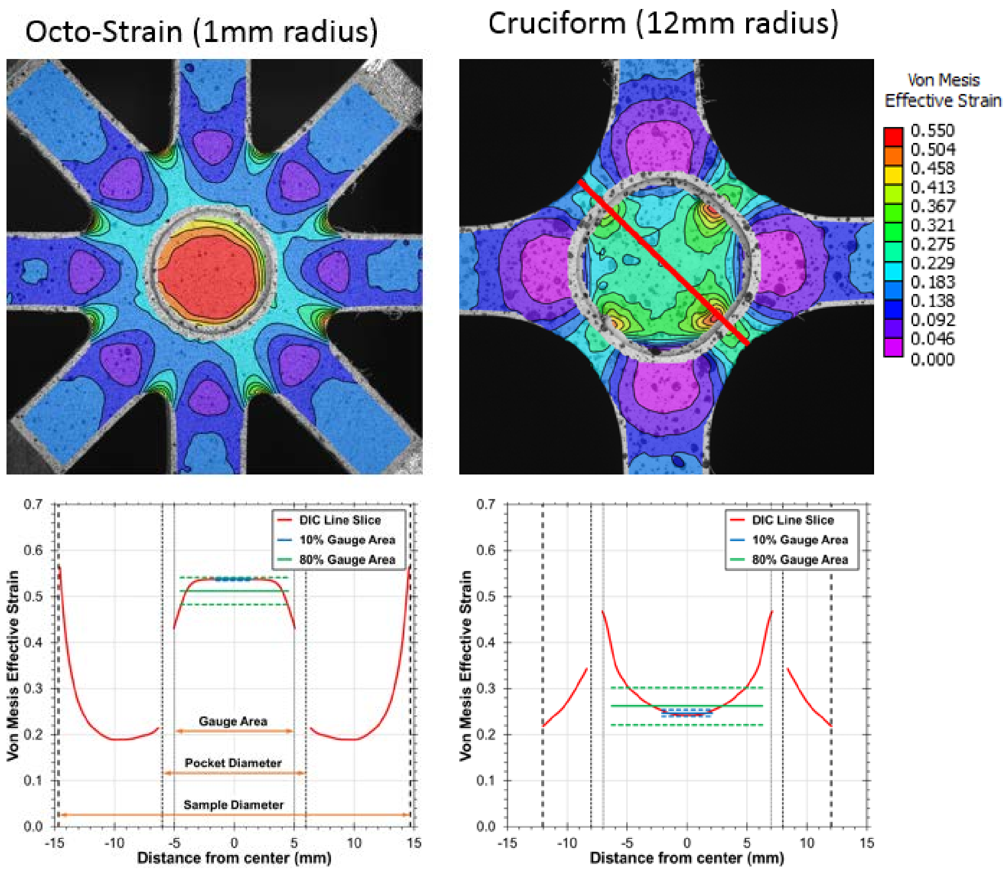


Figure 12: Strain Path of Octo-strain test specimen and cruciform

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Design Requirements

- 50 kN force applied to each of the eight loading arms
  - Allows for testing of High-Strength Metals
- Easy to assemble and make adjustments
- Keep weight of design under 500 pounds
  - Max. Capacity of 3-axis measurement table
- Stepper Motors cannot protrude from device
  - This will allow for an increased range of measurable scattering angles

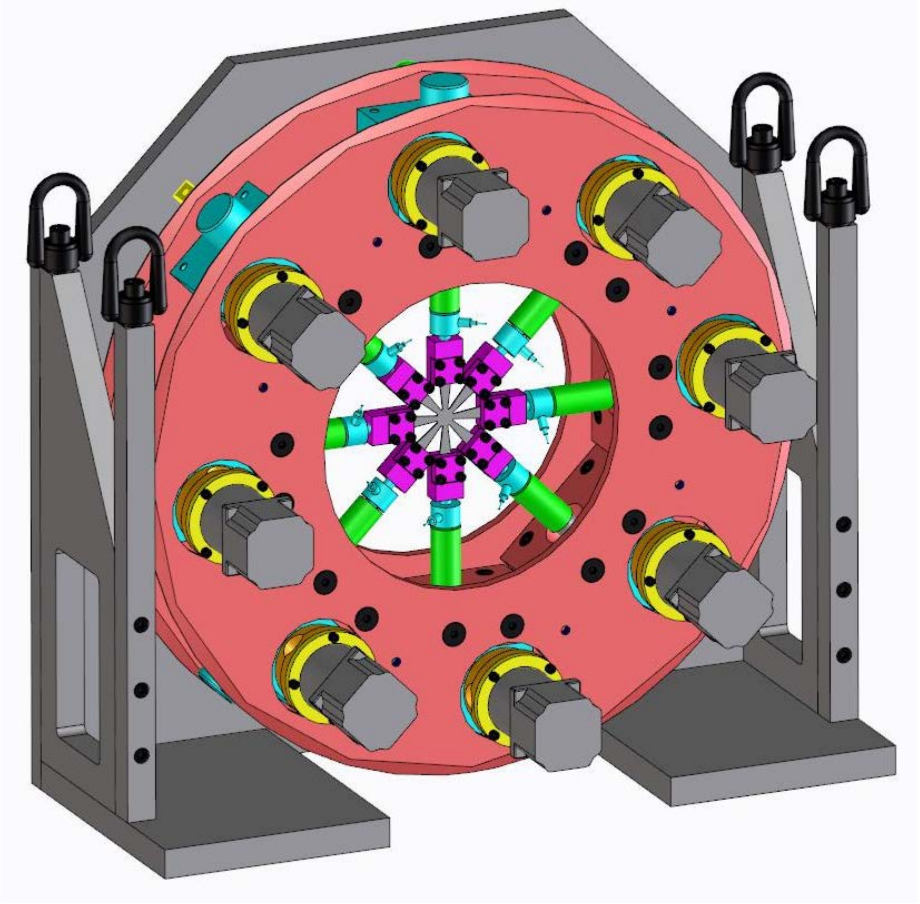

Figure 13: Previous 10 kN design

CAD Modeling

- Creo Elements direct drawing CAD software was used to model all components of Octo-Strain
- From 3D models, engineering drawings were made and sent to machine shop

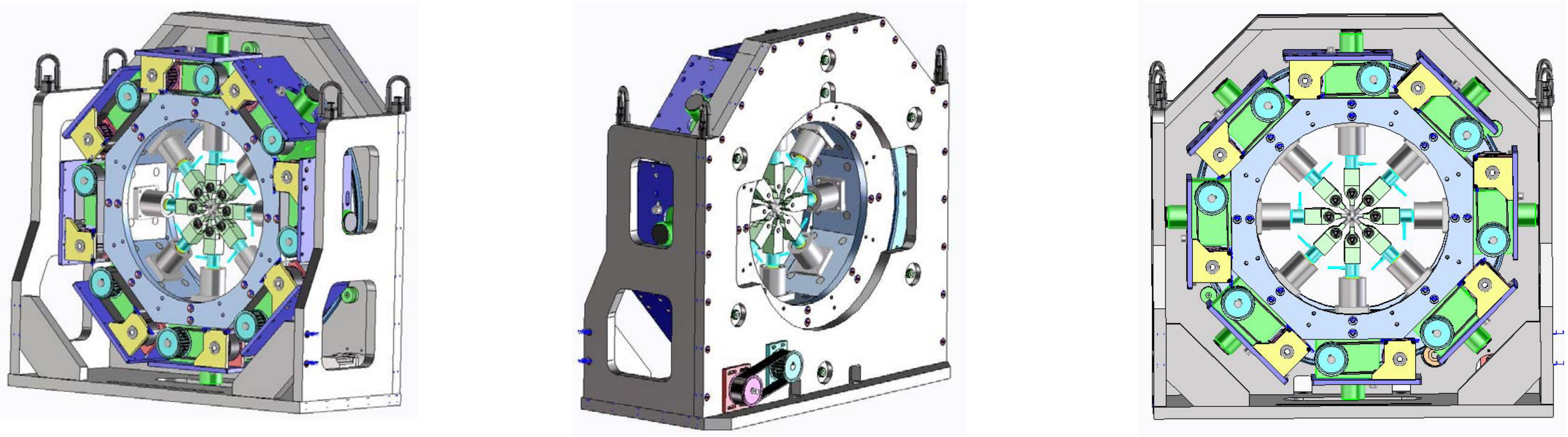

Figure 14: Isometric and Front View of Octo-Strain Device

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Drive System

- Determined a timing belt would work best for driving screw-jack
- Calculated Torque of 26.3 Nm to drive screw-jack
- 1:1 gear ratio, 25 tooth, 30 mm wide pulley
- Bearing eliminates radial load on motor shaft

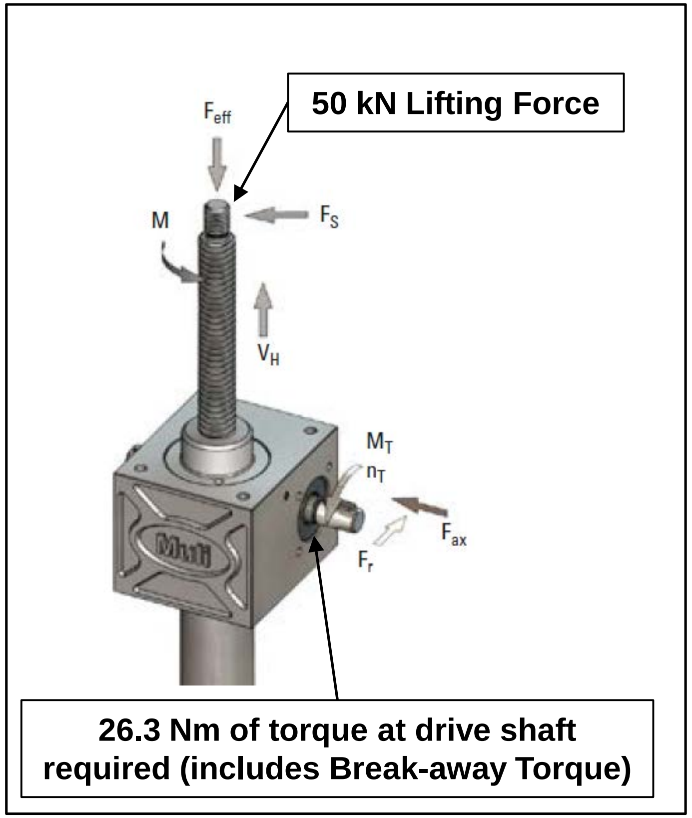


Figure 15: Free-body diagram of forces acting on screw-jack [4]

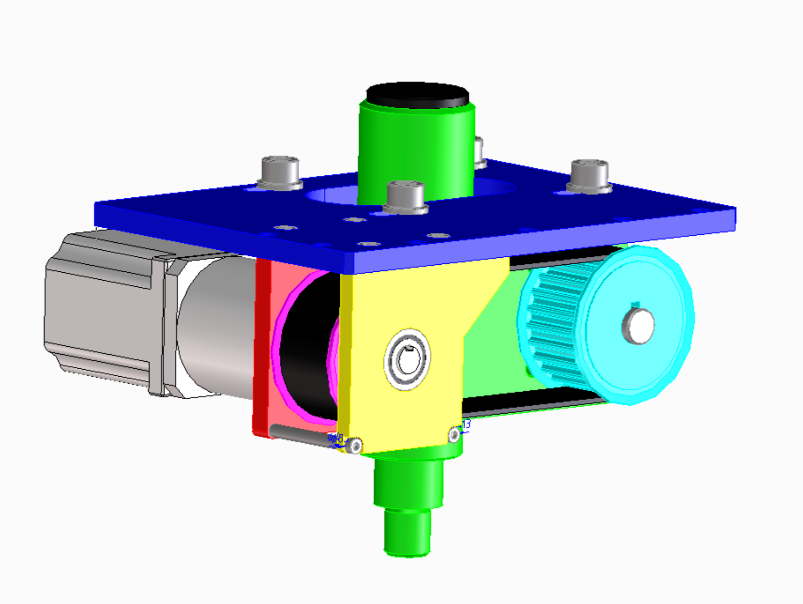


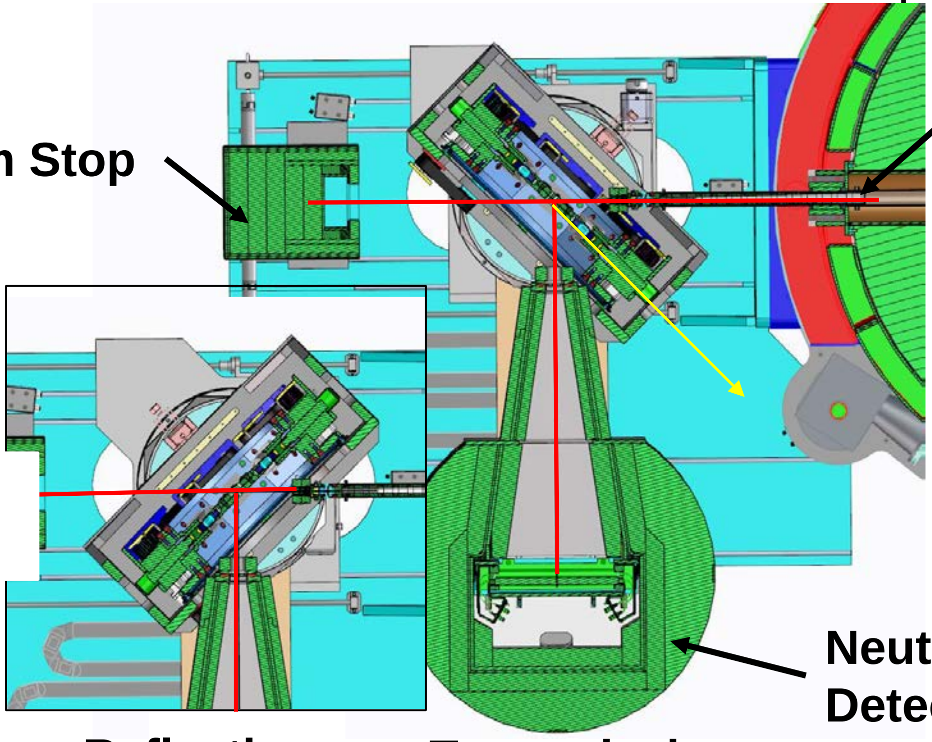
Figure 16: CAD model of completed drive assembly

Design Requirements- Continued

- Transmission and Reflection beam paths are possible
  - Provides Measurement of all three principle directions

Beam Stop

Primary Beam



Neutron Detector

Reflection

Transmission

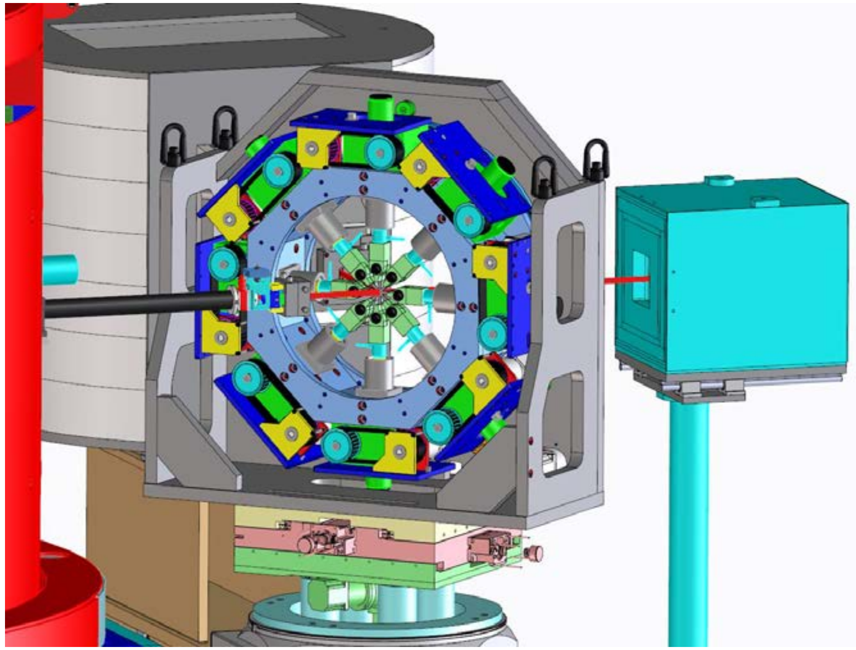


Figure 17: Top and Side View of BT8 Beam Path

FEA Results

- Determined max deflection of test stand when Device is assembled into base

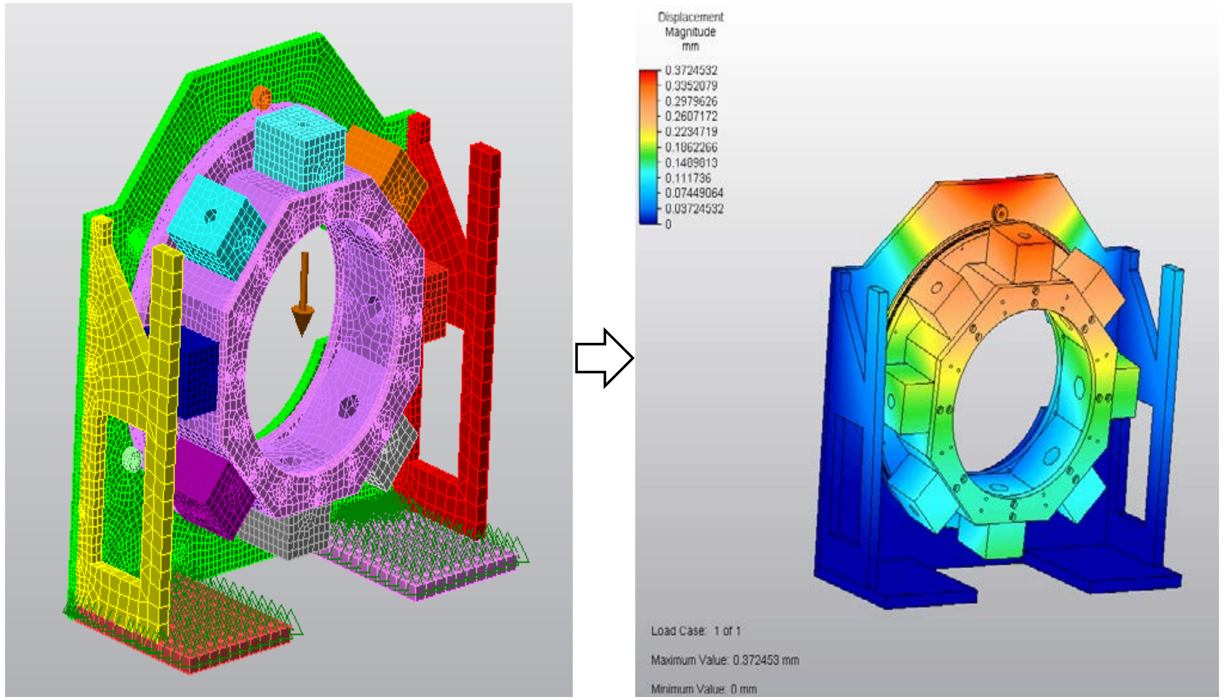


Figure 18: FEA Result of Max. Deflection due to gravity (0.37mm)

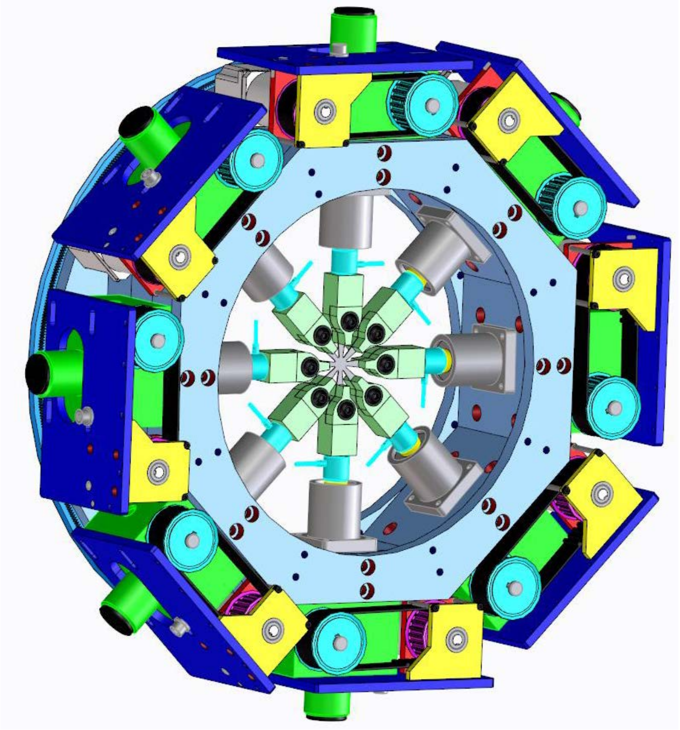


Figure 19: Assembled Octo-Ring without Test Stand

FEA Results- Continued

- Determined max deflection with loading condition of 50 kN (Compression)

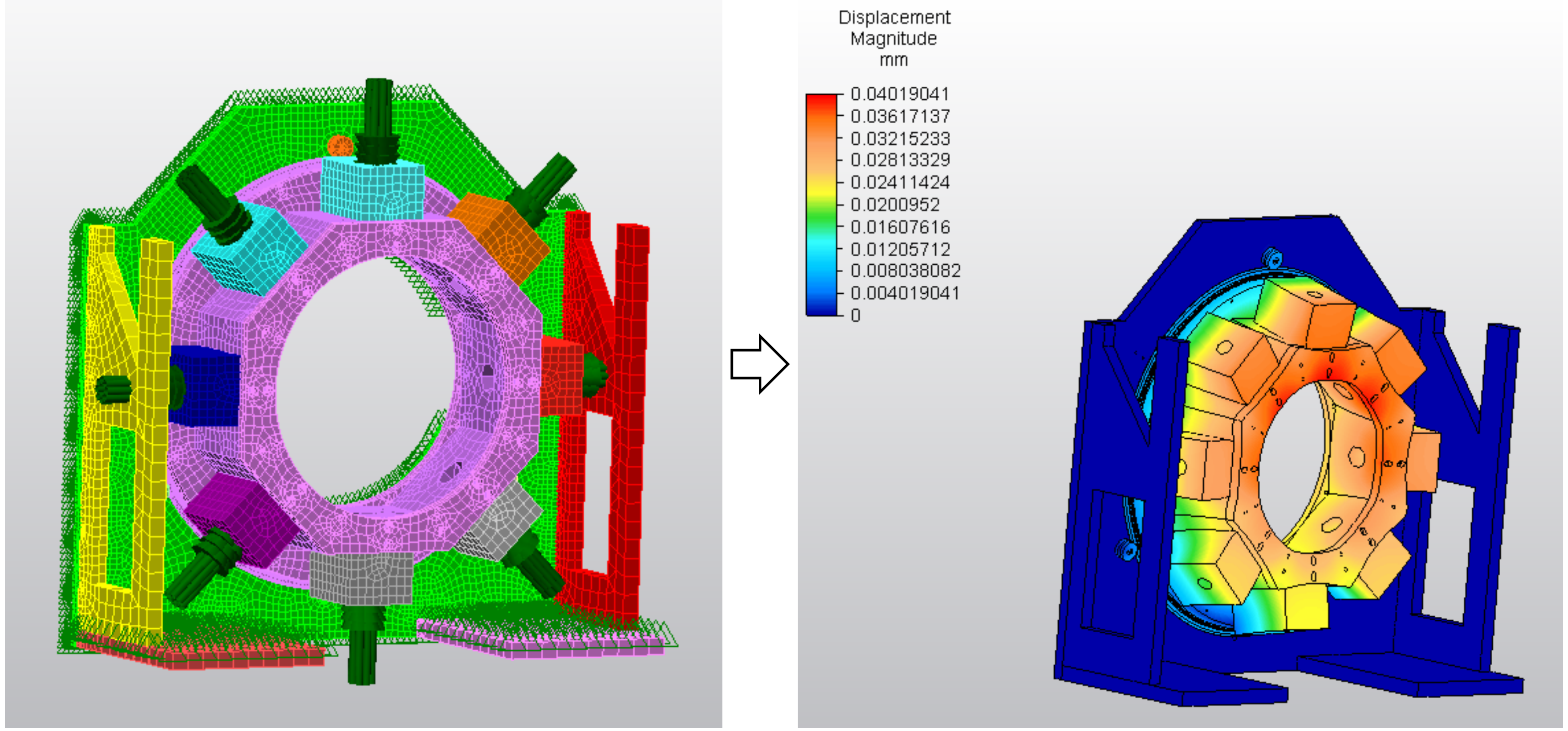
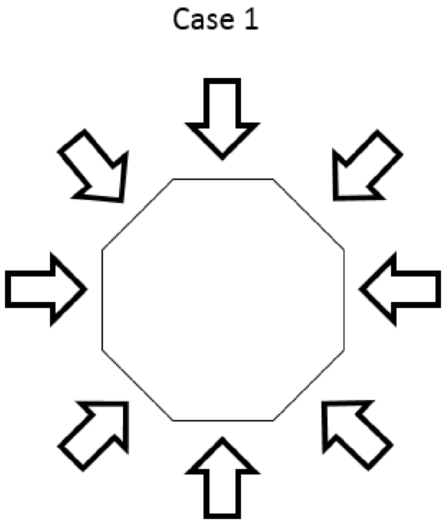


Figure 20: FEA Result of deflection due to 50 kN load in compression on Octo-Ring (0.04 mm)



Von Mises Stress
47.76 MPa
Yield Strength of
Aluminum 6061 =
276 Mpa

FEA Results- Continued

- Determined max deflection with loading condition of 50 kN (Tension)

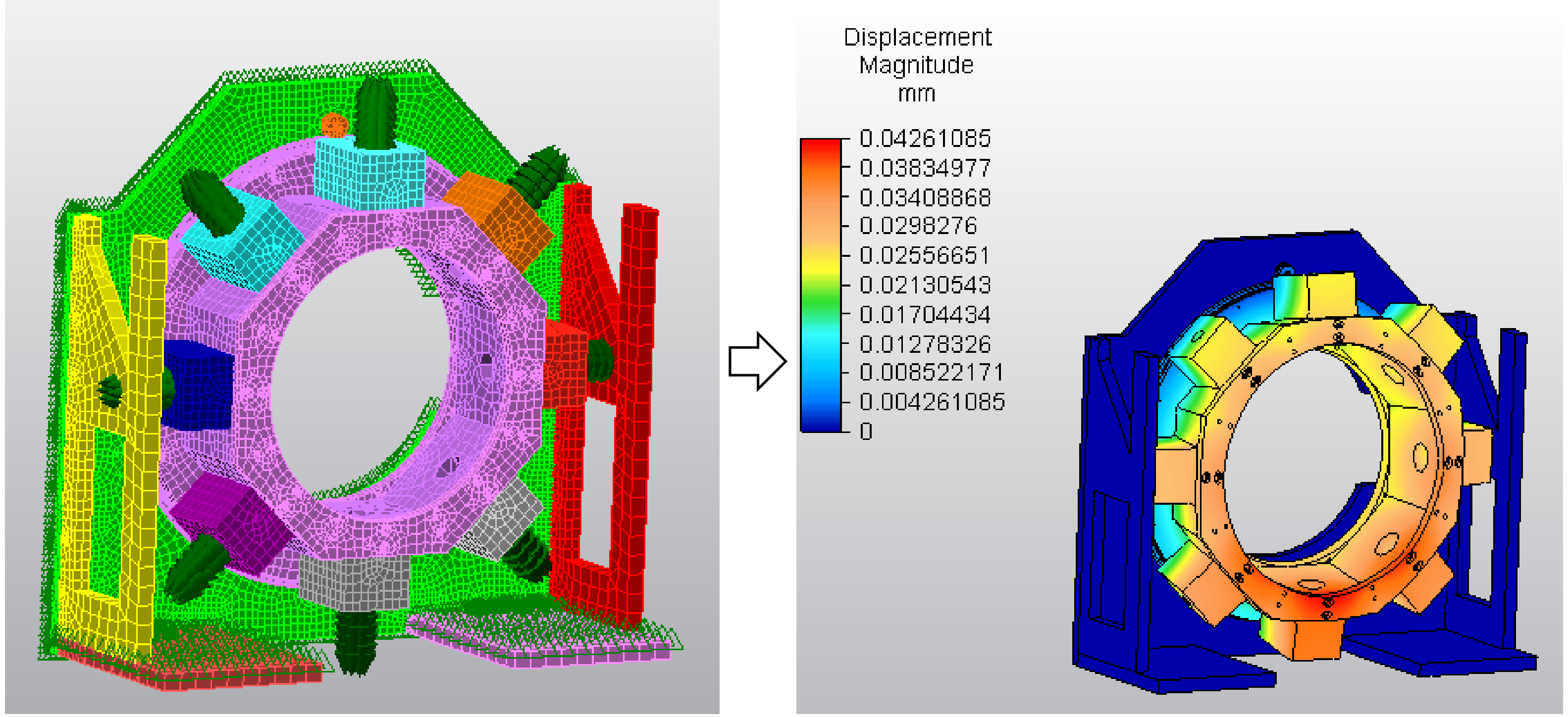
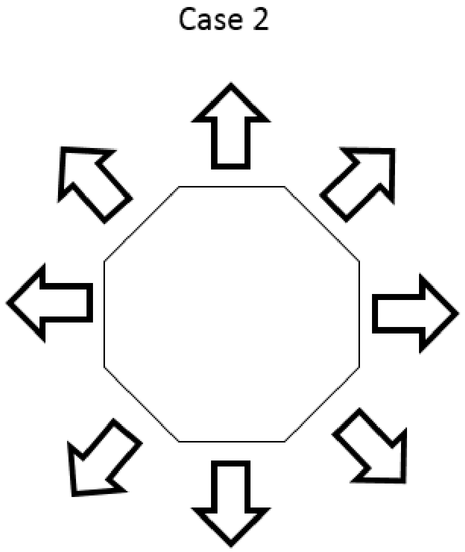


Figure 21: FEA Result of deflection due to 50 kN load in tension on Octo-Ring (0.04 mm)



Von Mises Stress
47.76 MPa
Yield Strength of
Aluminum 6061 =
276 Mpa

FEA Results- Continued

- Determined max deflection with worst case loading condition of 50 kN

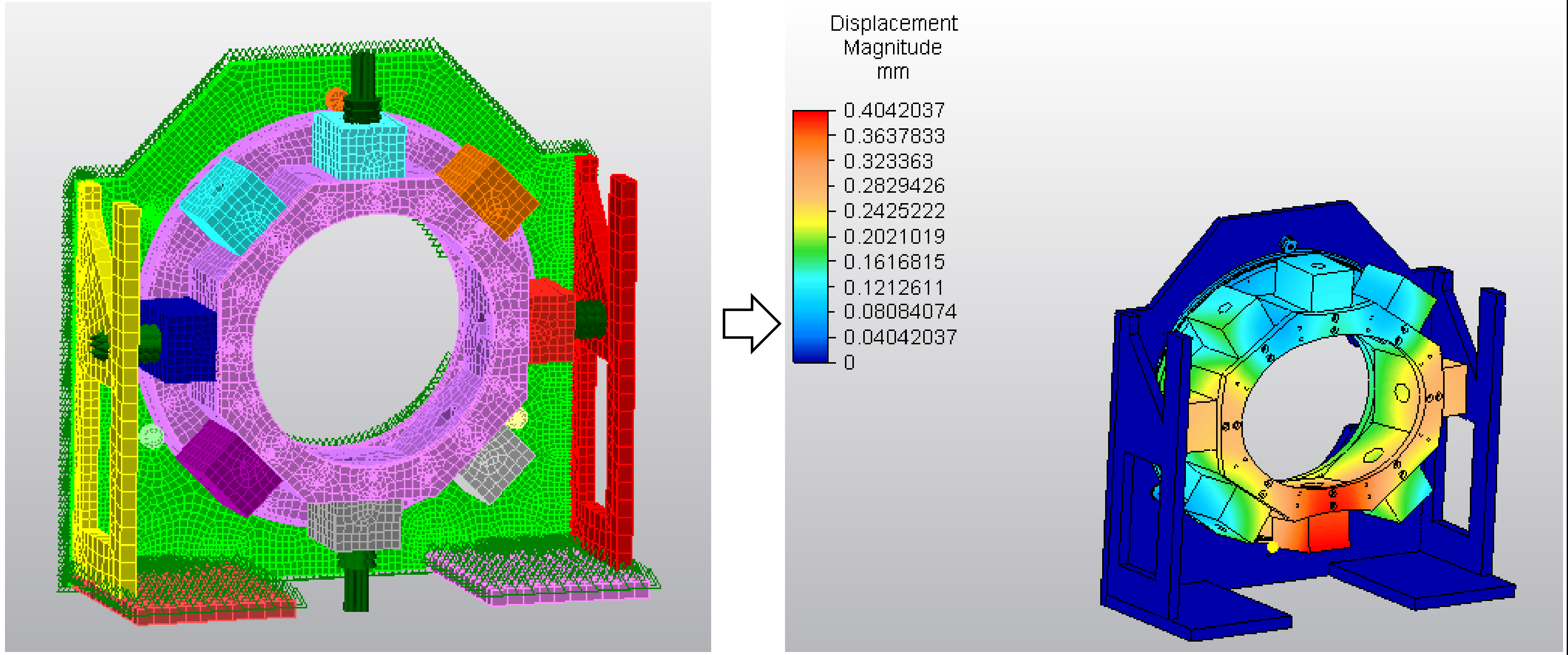
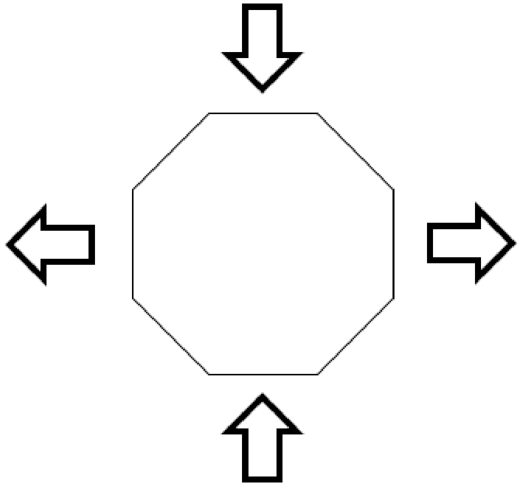


Figure 22: FEA Result of deflection due to 50 kN load on Octo-Ring (0.40 mm)

Case 3



Von Mises Stress 55.14 MPa
Yield Strength of Aluminum 6061 = 276 Mpa

Comparison of Designs

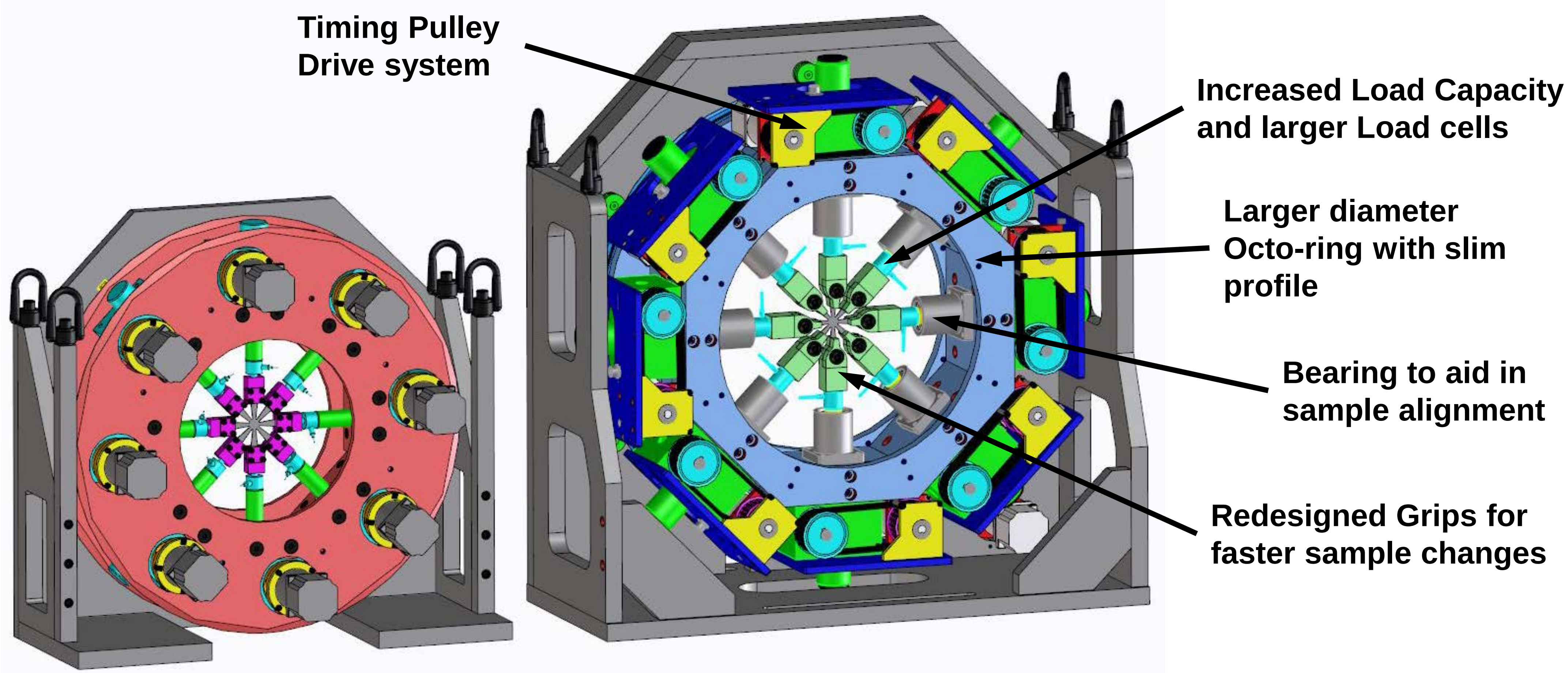


Figure 23: CAD model of 50 kN redesign compared to existing 10 kN design

Conclusions

- With this device, material property data will be collected that will lead to the adoption of generation three high strength steels in the automotive industry

- Increased load capacity
  - Allows for testing of high-strength metals

- By using pulley and drive system, significant space is saved
  - Increased range of measurable scattering angles

- FEA was performed to verify structural integrity of device

Future Work

- Get all parts machined from engineering drawings
- Assemble Octo-Strain device
- Begin Testing of high-strength metals

Acknowledgements

SURF Program

Dr. Justin Milner

Dr. Thomas Gnaupel-Herold

Dr. Julie Borchers

Dr. Joseph Dura

References

Questions?

[1] Courtesy of World Auto Steel

[2] Courtesy of Dr. Justin Milner

[3] Courtesy of Correlated Solutions

[4] "Worm Gear Screw Jacks." Thomsonlinear. Web.