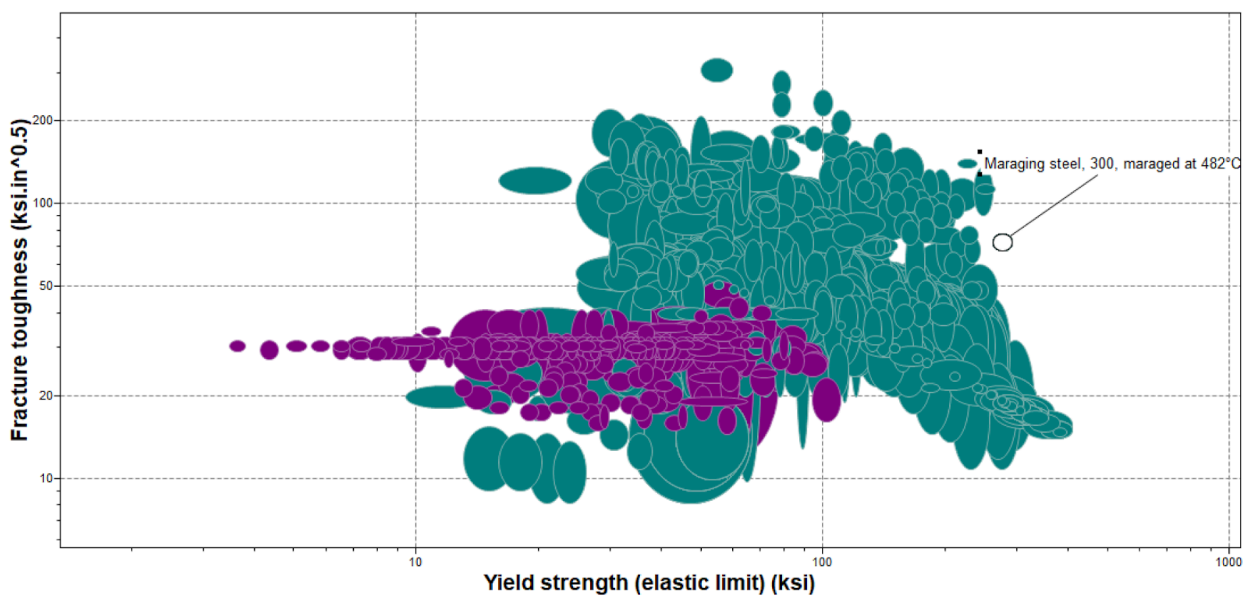
MAE 3270 Design Project: Torque Wrench

Sean Dempsey and Lea Staller

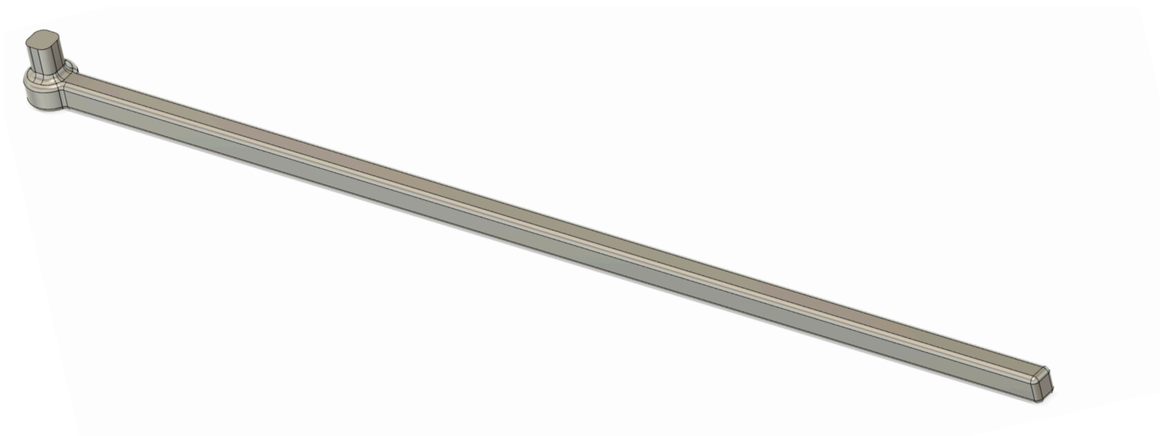
Design Goal

"The design goal is to maximize the voltage output of the wrench (mV/V) at the rated torque The design is required to attain at least 1.0 mV/V output at the rated torque of 600 in-lbf."

Using the MATLAB script, we found that the limiting factors in our design were yield strength and fracture toughness. Picking a material that has super high yield strength but is relatively brittle, such as M42 Tool Steel, wouldn't pass the fracture FOS. Compromising between the two factors, we picked Maraging steel 300. This allows for very high strains, which correspond to higher voltages from the strain gauge.

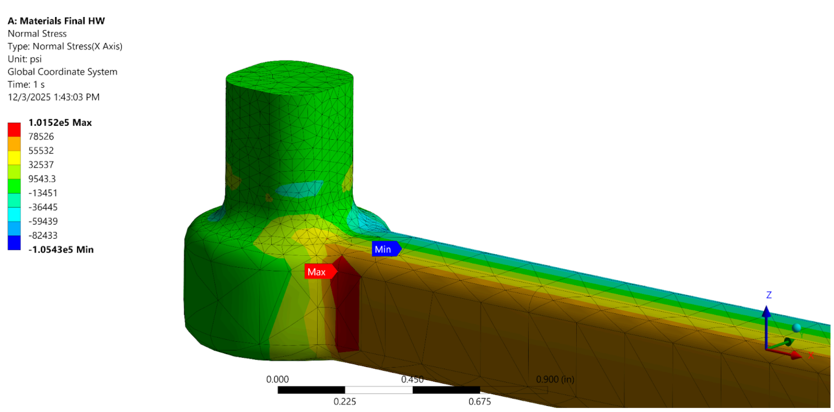


Original Design:



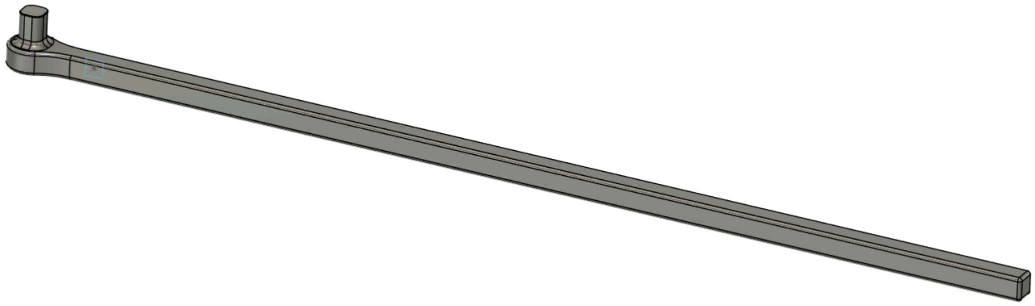
MATLAB Hand Calculations for Original Design
Material: Maraging Steel C300
Max Deflection: 1.253 inches
Max Stress: 71677.5 psi
Safety Factor against Yielding: 4.05
Safety Factor against Fracture: 2.72
Safety Factor against Fatigue: 2.16
Strain at Gauge (microstrain): 2408.5
Output Voltage (mV/V): **2.41**

FEA of Original Design: 101 ksi max normal stress with a FOS 2.87. There is a high stress concentration as the bar approaches the driver, where it transitions from a rectangular shaft to a larger circular mounting point.



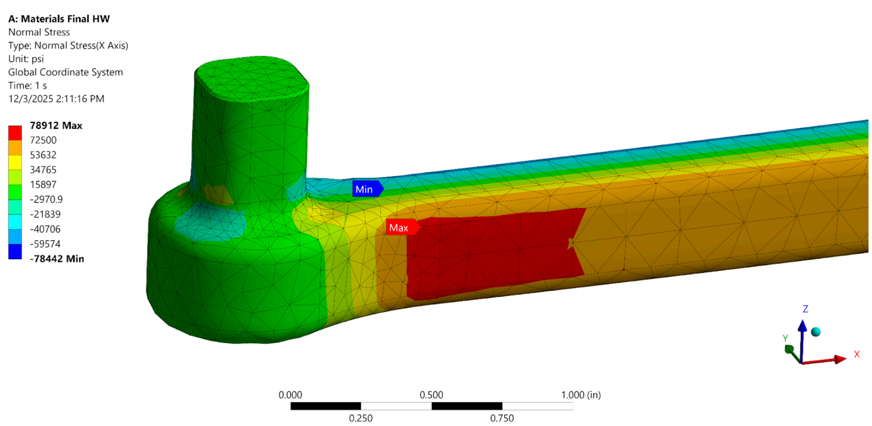
Two primary changes can be made to the design to increase the factor of safety: reducing the stress concentration around the transition area by increasing the fillet size, making the stress flow smoother, or increasing the size of the handle to have a larger moment area of inertia, decreasing the bending stress in the beam.

Final FEA optimized design:



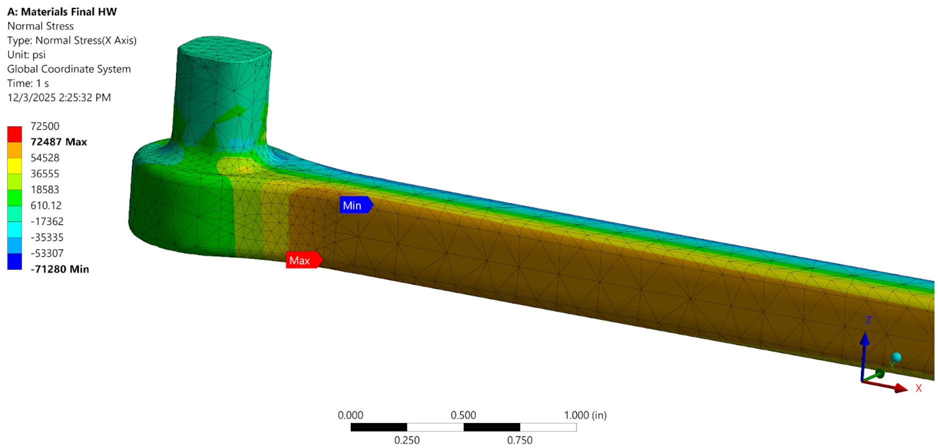
MATLAB Hand Calculations for Final Design:
Material: Maraging Steel C300
Max Deflection: 1.114 inches
Max Stress: 68266.7 psi
Safety Factor against Yielding: 4.25
Safety Factor against Fracture: 2.86
Safety Factor against Fatigue: 2.27
Strain at Gauge (microstrain): 2370.4
Output Voltage (mV/V): **2.37**

Iteration 1: In the first iteration, we changed the CAD model to have a larger fillet as a way to improve stress flow from the bar to the driver, but the stress is still above the allowable stress. This design has an FOS of 3.67, an improvement but still below the required FOS of 4.



This design change doesn't affect the main design goal of optimizing strain-gauge voltage output because the beam cross-section remains unchanged, so the strain at the gauge location doesn't change. The strain gauge is located 1 in from the center of the drive so that the stress concentrations around the changing geometry don't affect the strain gauge. Increasing the fillet size did not significantly affect the strain distribution at the strain gauge, so it can remain in the same location.

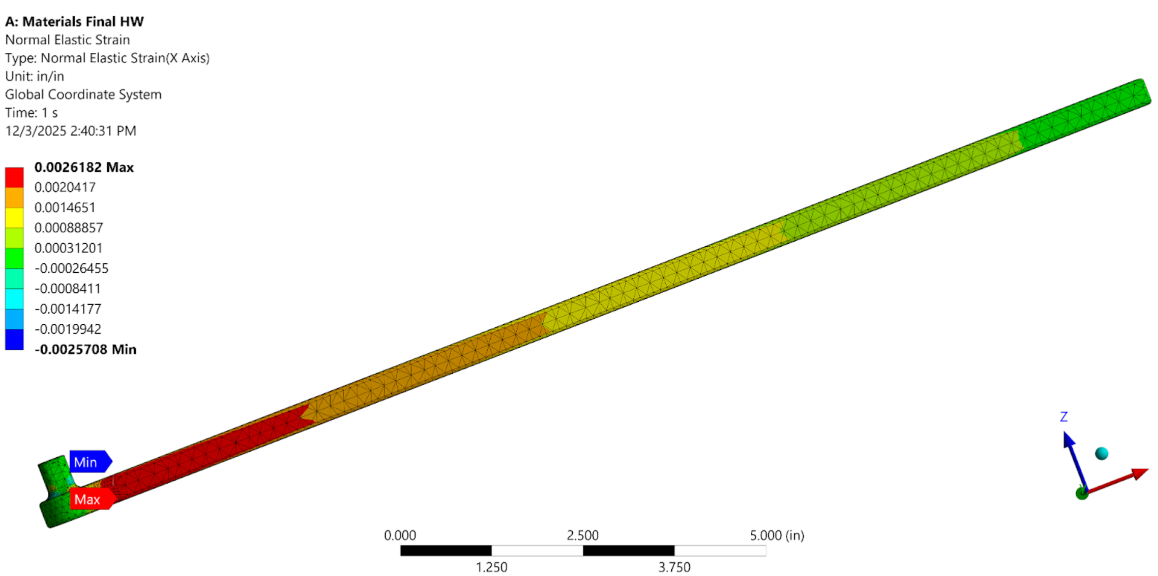
Final Iteration (2): We were still getting too high stress around the fillet location, so we changed the height (h) and width (b) of the handle beam to be slightly larger.



Both the height and width were changed to 0.375 in, which increased the hand-calculated FOS to 4.25.

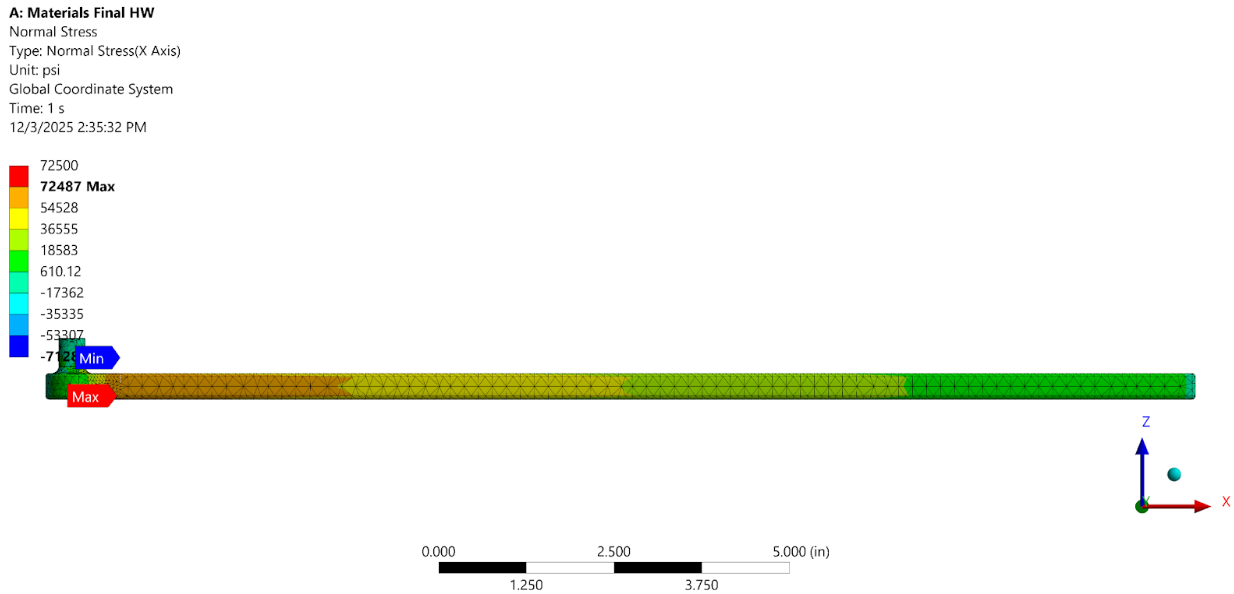
Referencing the FEM results, the FOS to yield is 4.00 exactly.

This change reduced strain because the bar's stiffness increased. This results in a decrease in output voltage from the strain gauge. In the FEM model, compared to the hand calculations, there is more strain at the strain gauge location. We calculated there should be 2370.4 microstrain, and when running the FEA, we got a strain at the gauge of 2425 microstrain. This results in a 2.2% difference, which is not significant enough for concern. The handle of the torque wrench can be very closely approximated as a beam in bending, resulting in very similar strains.



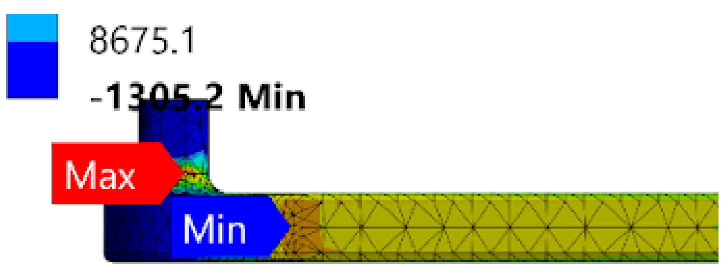
The hand-calculated maximum normal stress is 68266.7 psi, and the FEM maximum normal stress is 72487 psi.

Percent difference: $\frac{72487 - 68266.7}{(72487+68266.7)/2} \times 100$ = 6.0%



The two values do not differ significantly, having a small percent difference of 6.0%. The reason they are not that different is because the stress concentration in the FEM is smoothed out by the large fillet located between the changes in geometry. There is a difference because beam theory does not account for this change in geometry and stress concentration, but it does a decent job given the fillet's general location on the main part of the rod.

The normal stress was used because it accurately represents the bending stress in the beam and ignores artificial stress risers due to boundary conditions.

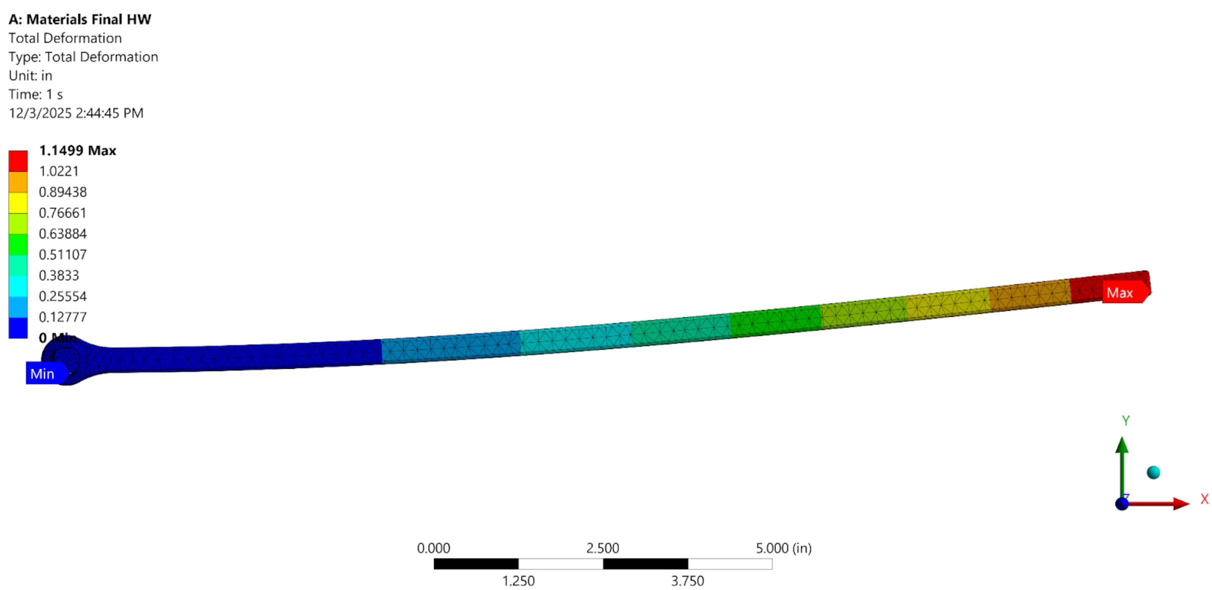


As you can see in this image of the maximum principle stress, the maximum is at the boundary condition contact. The contact is not accurately modeled, and the stress riser shouldn't be considered.

The hand-calculated displacement is 1.114 in, and the FEM displacement is 1.1499”.

Percent difference: $\frac{1.1499 - 1.114}{(1.1499+1.114)/2} \times 100$ = 3.2%

The two values do not differ significantly, having a small percent difference of 3.2%. The reason they do not differ much is because the handle part is essentially just a beam in bending, which is exactly how the hand calculations go about solving for this displacement.



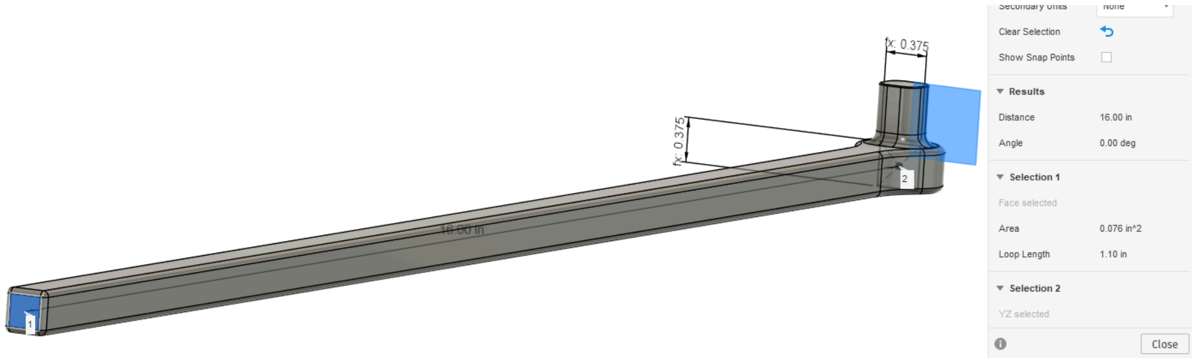
The beam-theory MATLAB script provides a reasonably accurate representation of the model, as the mesh lines remain roughly straight as the handle deforms. The mesh lines are straight over short distances and, as you “zoom out,” they compound and stay straight.

Strain Gauge:

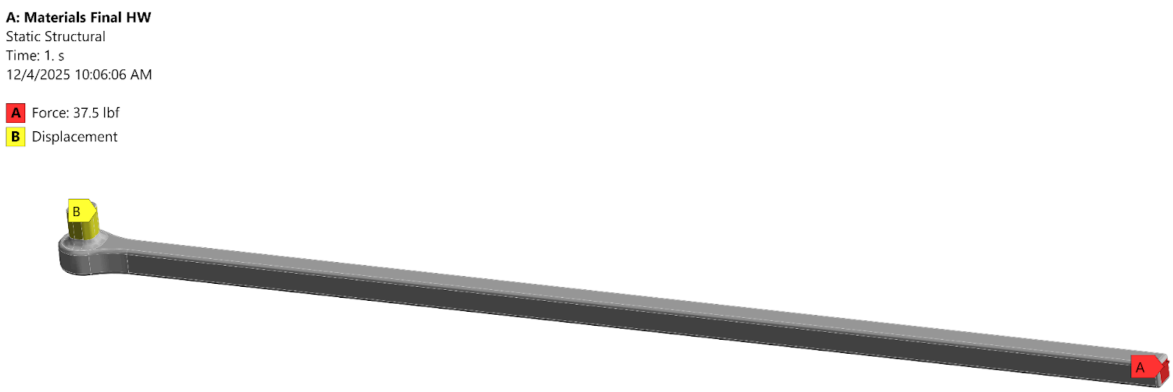
We selected the strain gauge model SGD-1.5/120-LY11 because it met all our specifications for size and material. The dimensions are as follows: 4.7 mm by 3.4 mm → 0.185 in by 0.134 in. This is small enough to easily fit on the side of the torque wrench, ensuring that the design can be manufactured.

More Images

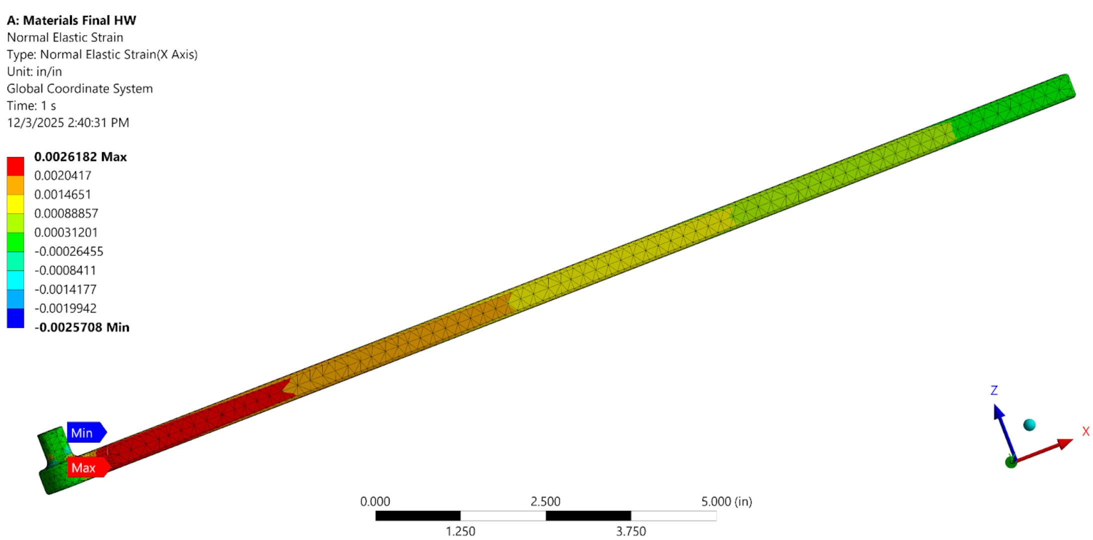
CAD model w/ dimensions:



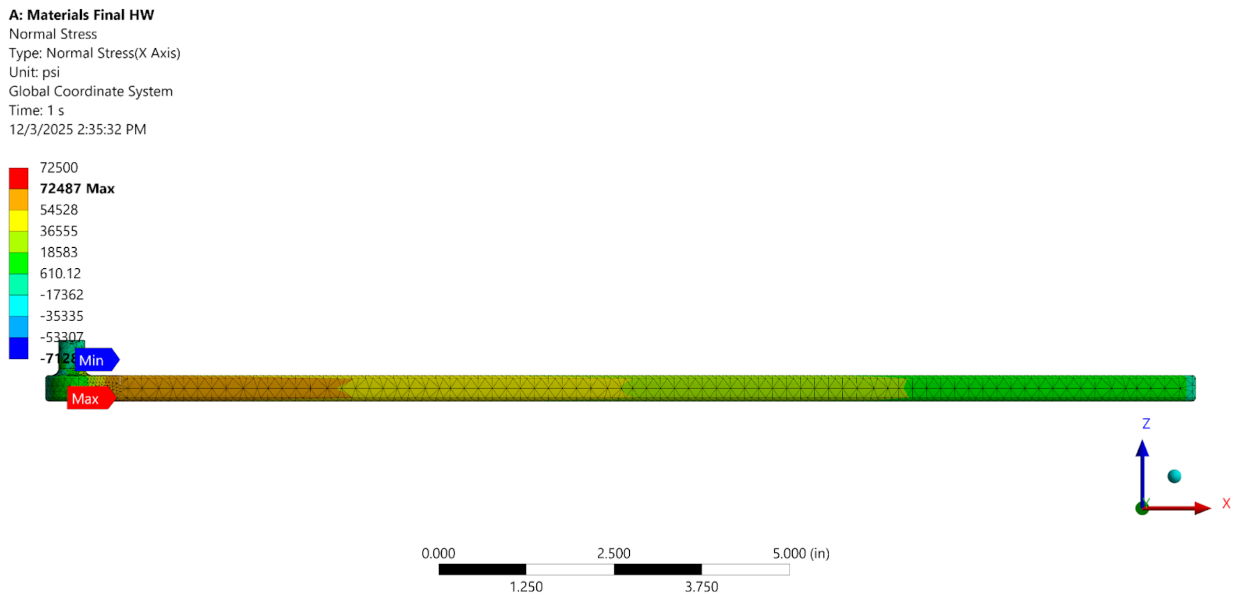
FEA Set up:



Normal Elastic Strain:



Normal stress contours:



Max principal stress contours: