MAE 3270 Design Project: Torque Wrench

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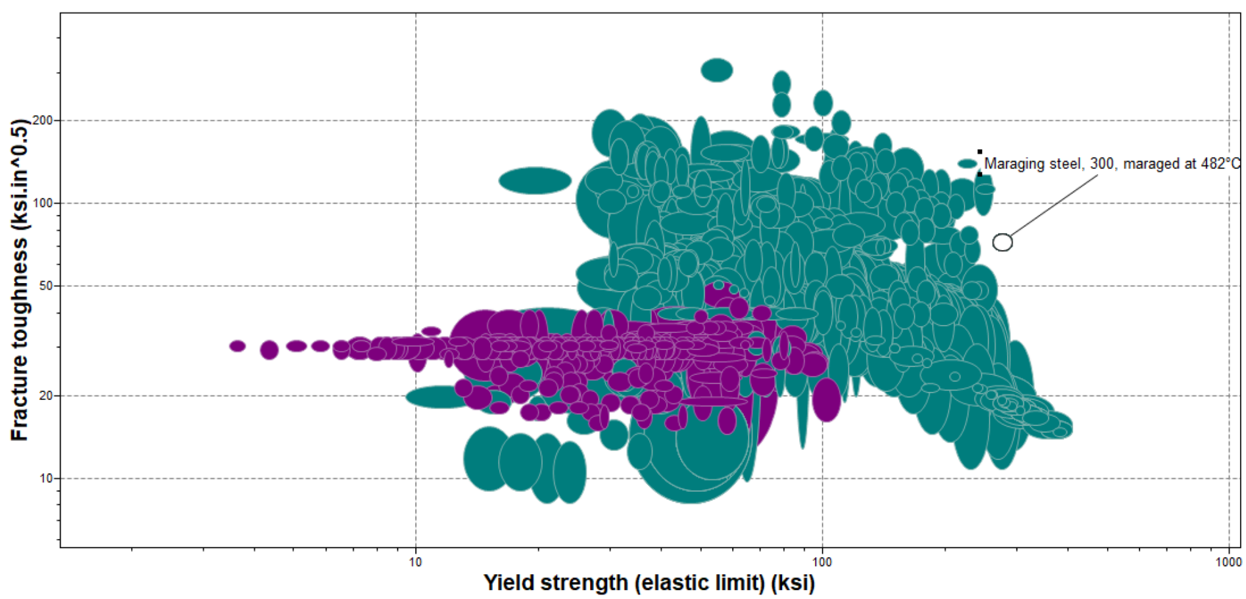
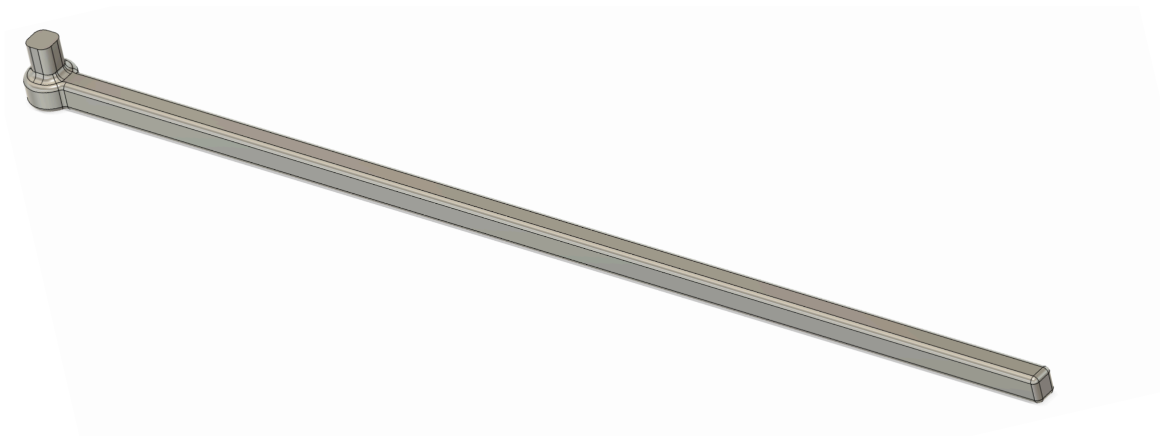
Design Goal

"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

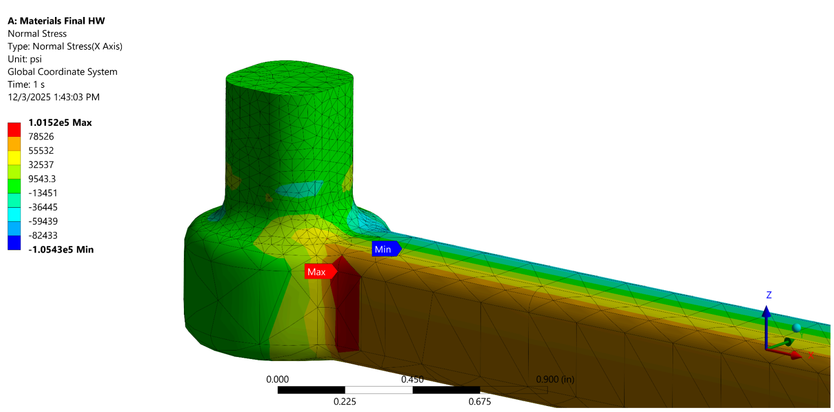
Safety Factor against Fracture: 2.72

Safety Factor against Fatigue: 2.16

Strain at Gauge (microstrain): 2408.5

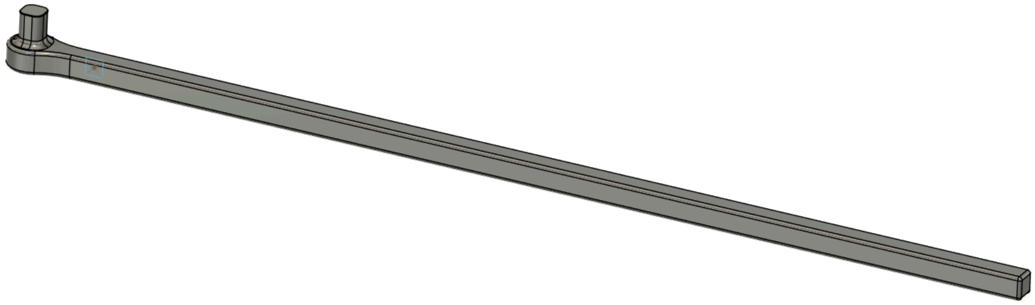
Output Voltage (mV/V): **2.41**

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.



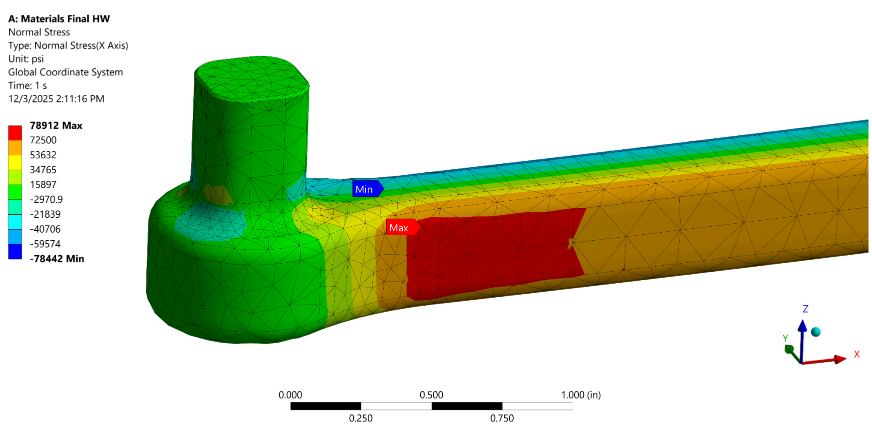
There are two primary changes that can be made to the design to increase the factor of safety: reducing the stress concentration around the transition area by increasing the fillet size making the stress flow smoother, and the other option is to increase the size of the the handle to have a larger moment area of inertia decreasing the bending stress in the beam.

Final FEA optimized design:



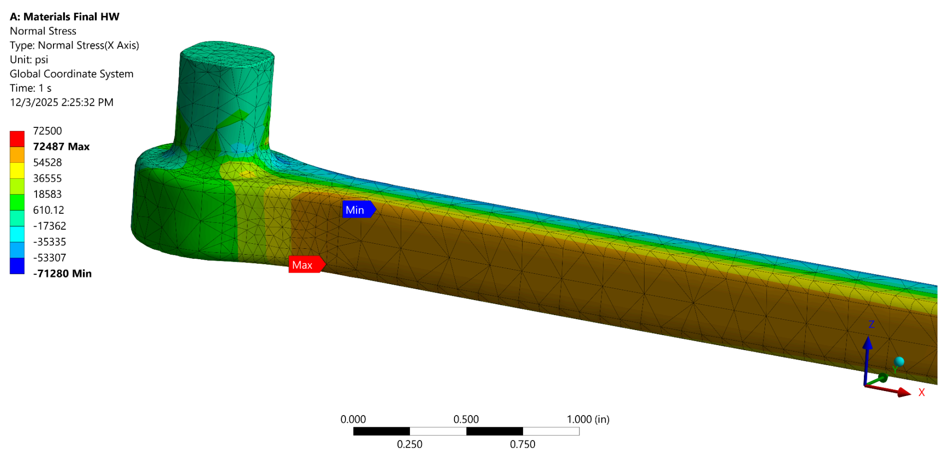
Matlab Hand Calculations for Final Design:
Material: Maraging Steel C300
Max Deflection: 1.114 inches
Max Stress: 68266.7 psi
Safety Factor against Yielding: 4.25
Safety Factor against Fracture: 2.86
Safety Factor against Fatigue: 2.27
Strain at Gauge (microstrain): 2370.4
Output Voltage (mV/V): **2.37**

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, which is an improvement but not above required FOS of 4.



This design change doesn't affect the main design goal of optimizing strain gadge voltage output because the crosssection of the beam doesn't change so the strain at the gauge location doesn't change. The strain gadget is located 1 in from the center of the drive so that the stress concentrations around the changing geometry doesn't affect the strain gauge. Increasing the fillet size did not significantly impact the strain distribution at the strain gauge, so it can be kept in the same location.

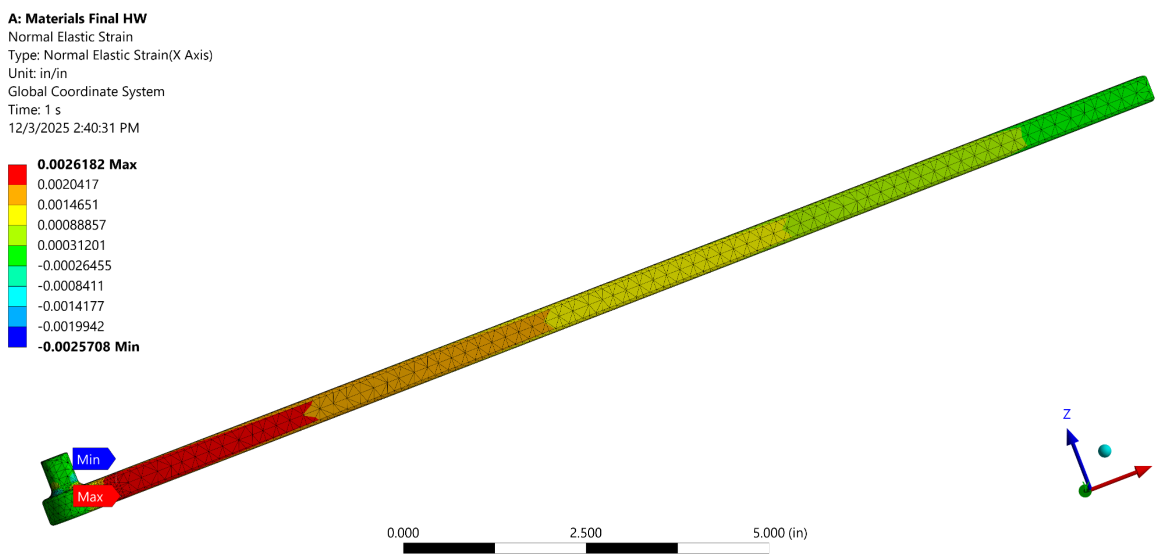
Final Iteration (2): We were still getting too high stress around the fillet location, so we changed the height (h) and width (b) of the handle beam to be slightly larger.



The height and width both were changed to 0.375in, which resulted in an increased the hand calculations FOS to 4.25.

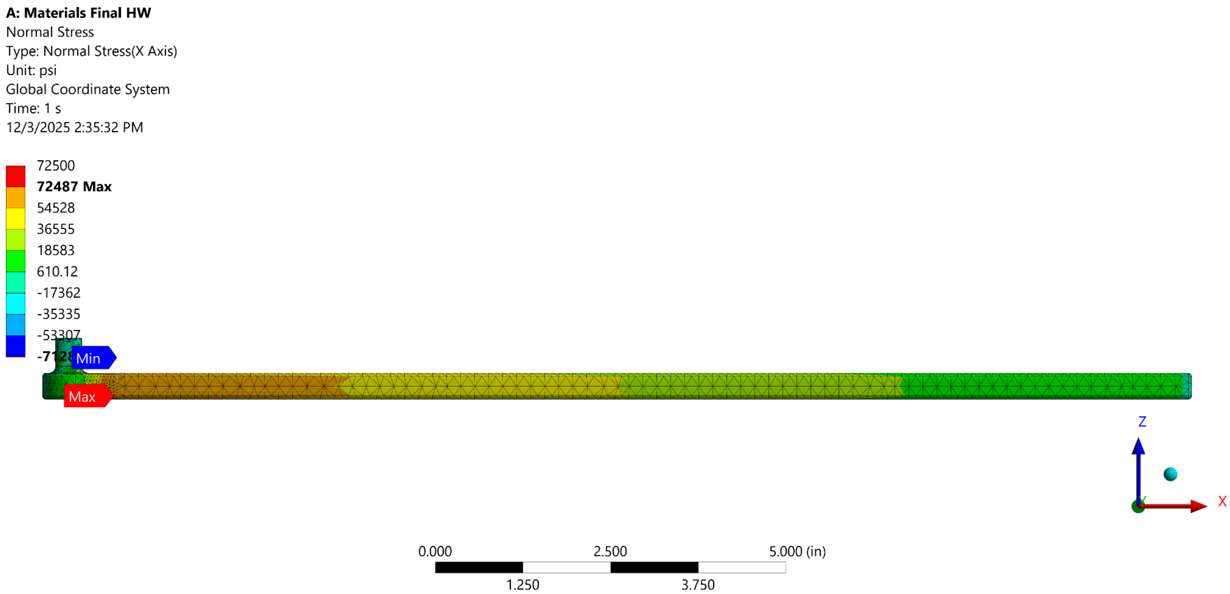
Referencing the FEM results the FOS to yield is 4.00 exactly.

This change decreased the amount of strain because the stiffness of the bar increased. This results in a decrease of 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 2370.4microstrain and when running the FEA we got a strain at 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 which results in very similar strains.



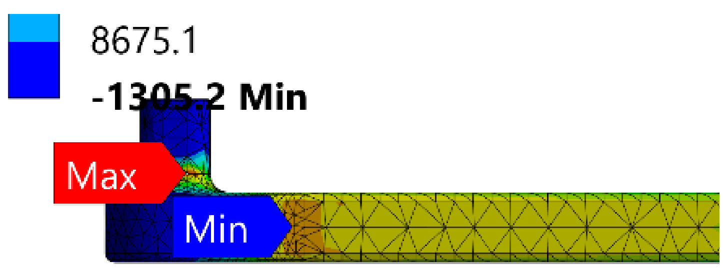
The hand-calculated maximum normal stress is 68266.7 psi, and the FEM maximum normal stress is 72487 psi.

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



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 the beam theory does not account for this change in geometry and stress concentration, but it does a decently good job due to the general location of this fillet, as it is 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

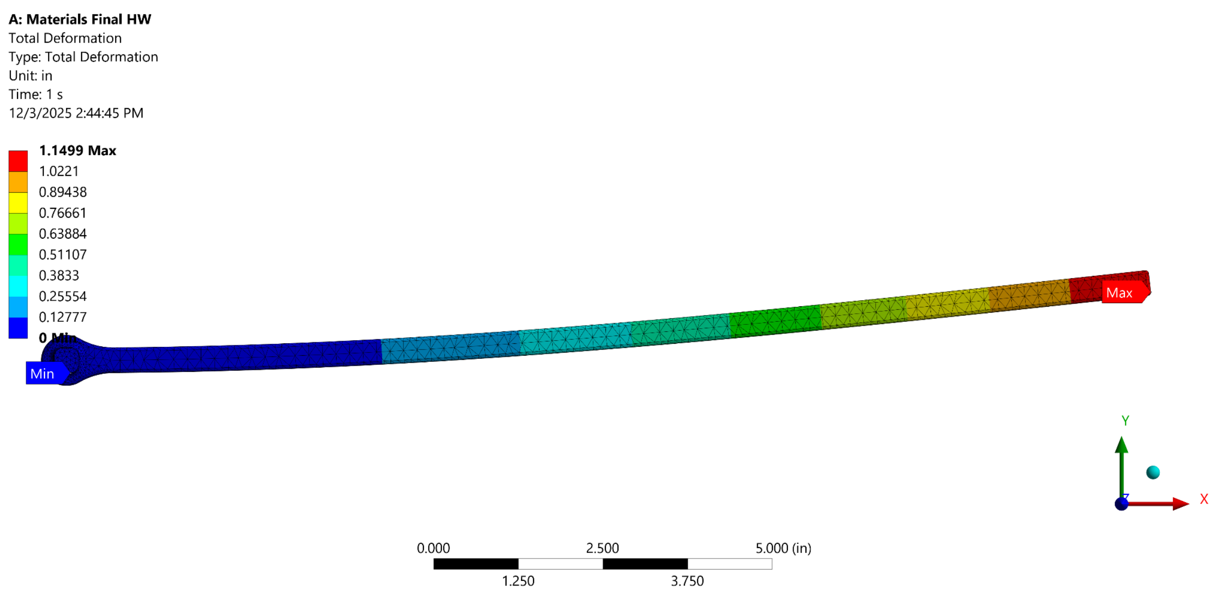


As you can see in this image of the maximum principle stress the Max is at the boundary condition contact. The contact is not accurately modeled and the stress riser shouldn't be considered.

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

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

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.



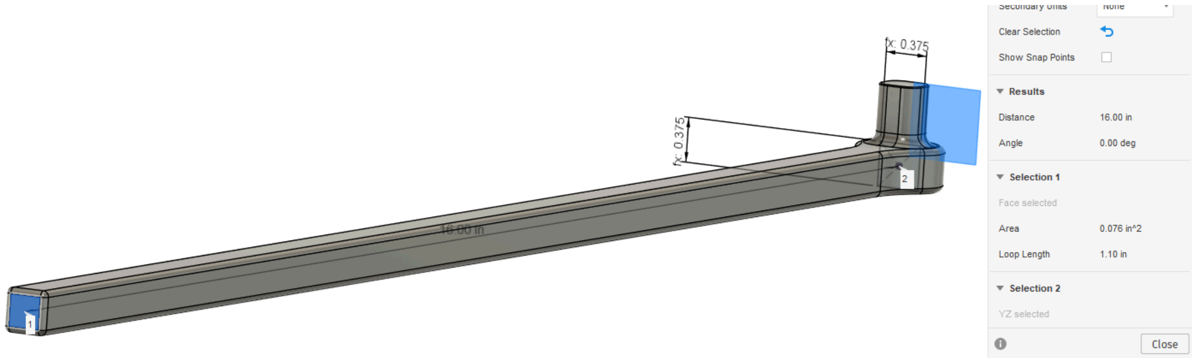
The beam theory matlab script is a reasonably accurate representation of the model, as the mesh lines remain roughly straight as the handle deforms. The mesh lines are straight over short distances and, as you "zoom out," they compound and stay straight.

Strain Gauge:

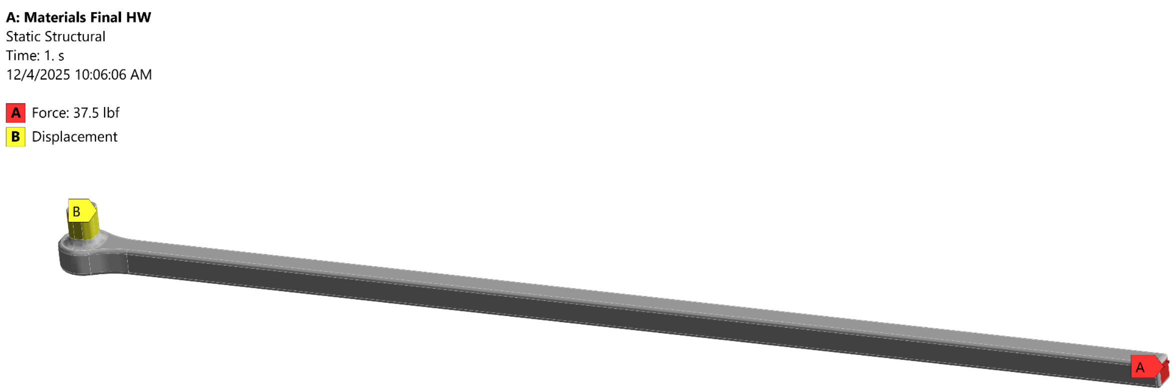
We selected the strain gauge model SGD-1.5/120-LY11 as it met all of our specifications for size and material type. The dimensions are as follows: 4.7 mm by 3.4 mm → 0.185 in by 0.134 in. This is small enough to easily fit on the the side of the torque wrench ensuring that the design can be manufactured.

More Images

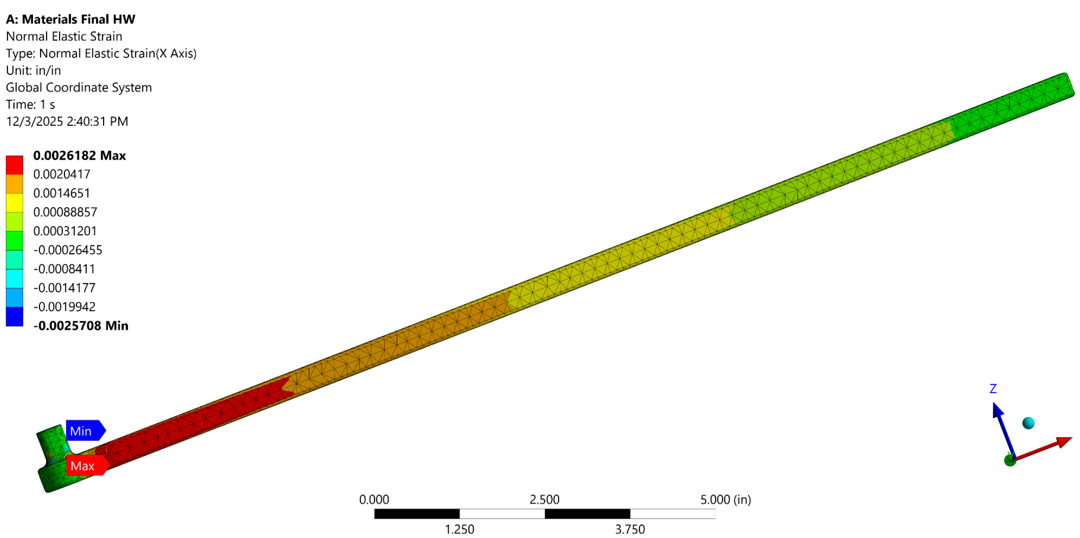
CAD model w/ dimensions:



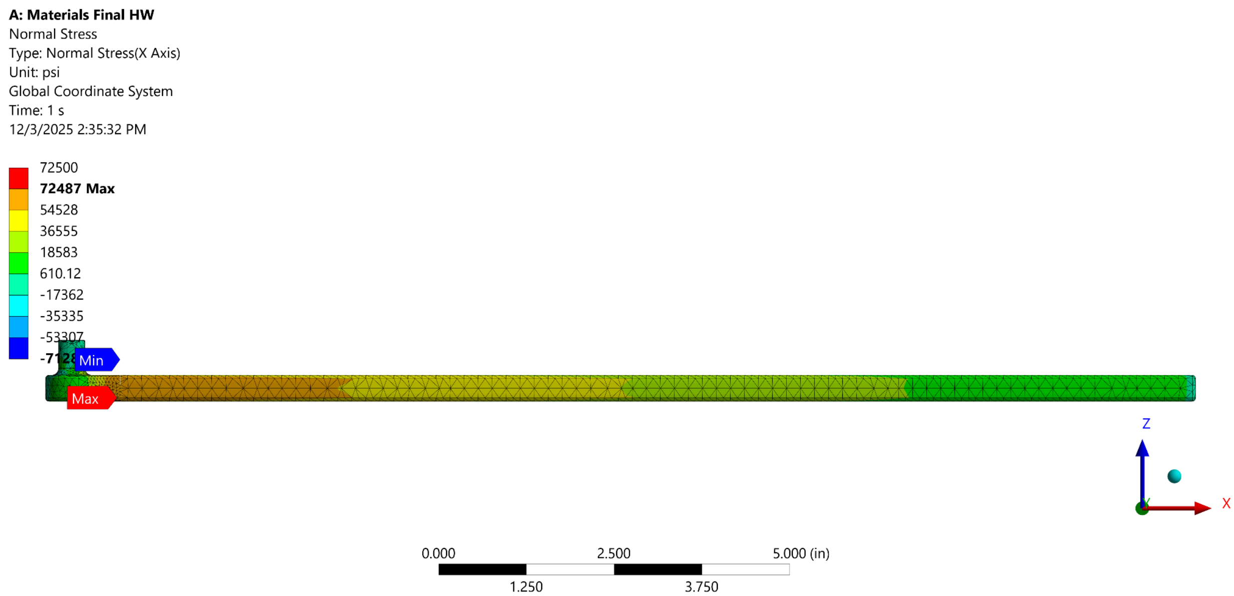
FEA Set up:



Normal Elastic Strain:



Normal stress contours:



Max principal stress contours: