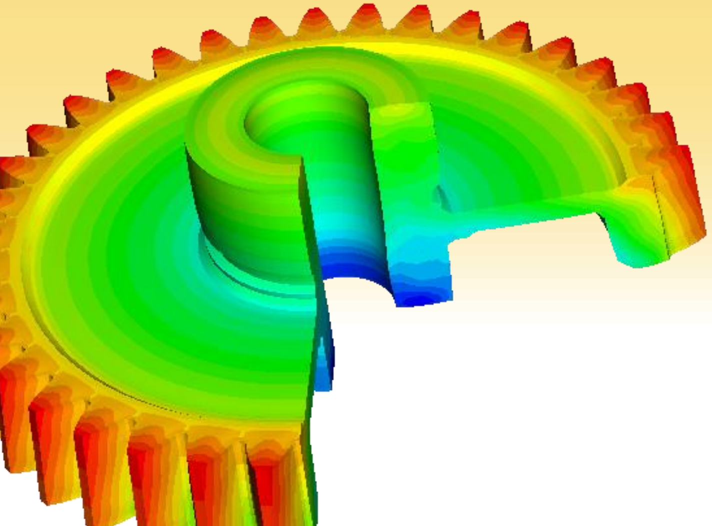
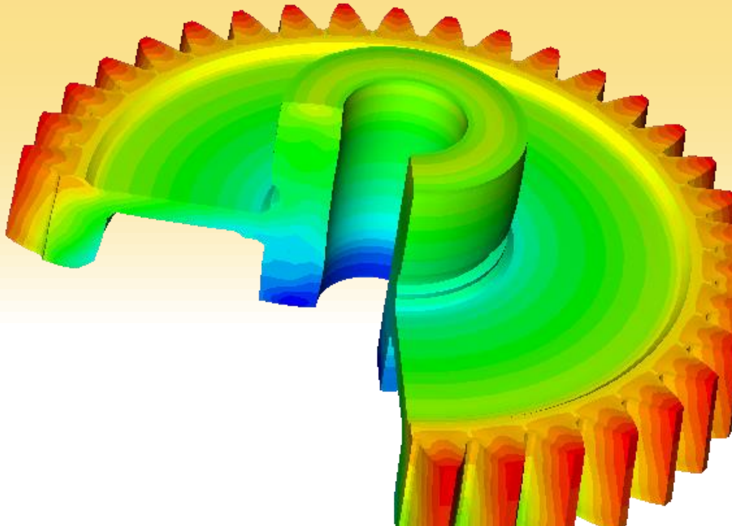
Using DANTE during Product Design

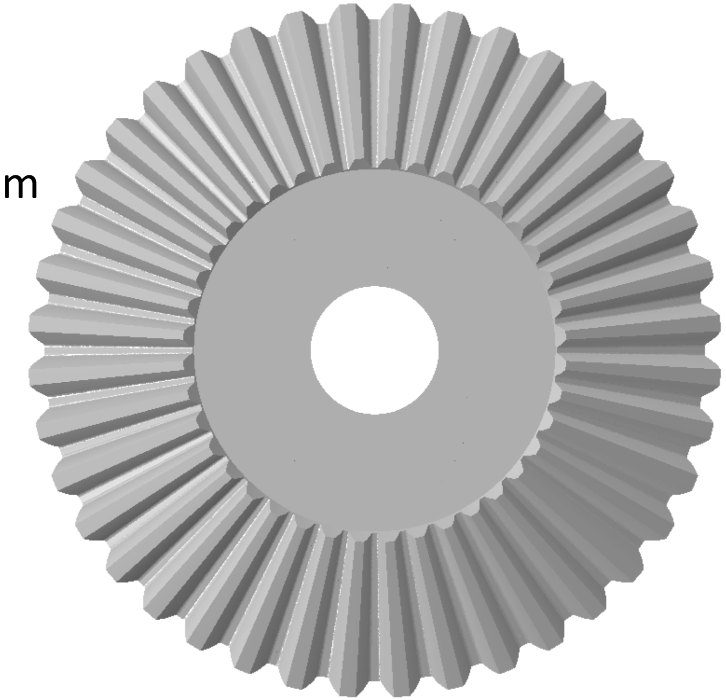
Correcting Bevel Gear Distortion from Heat Treat

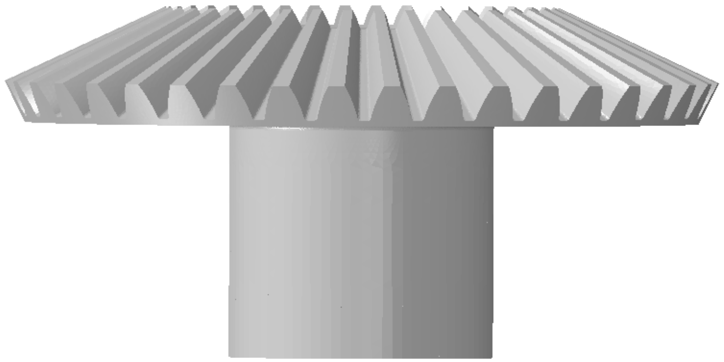


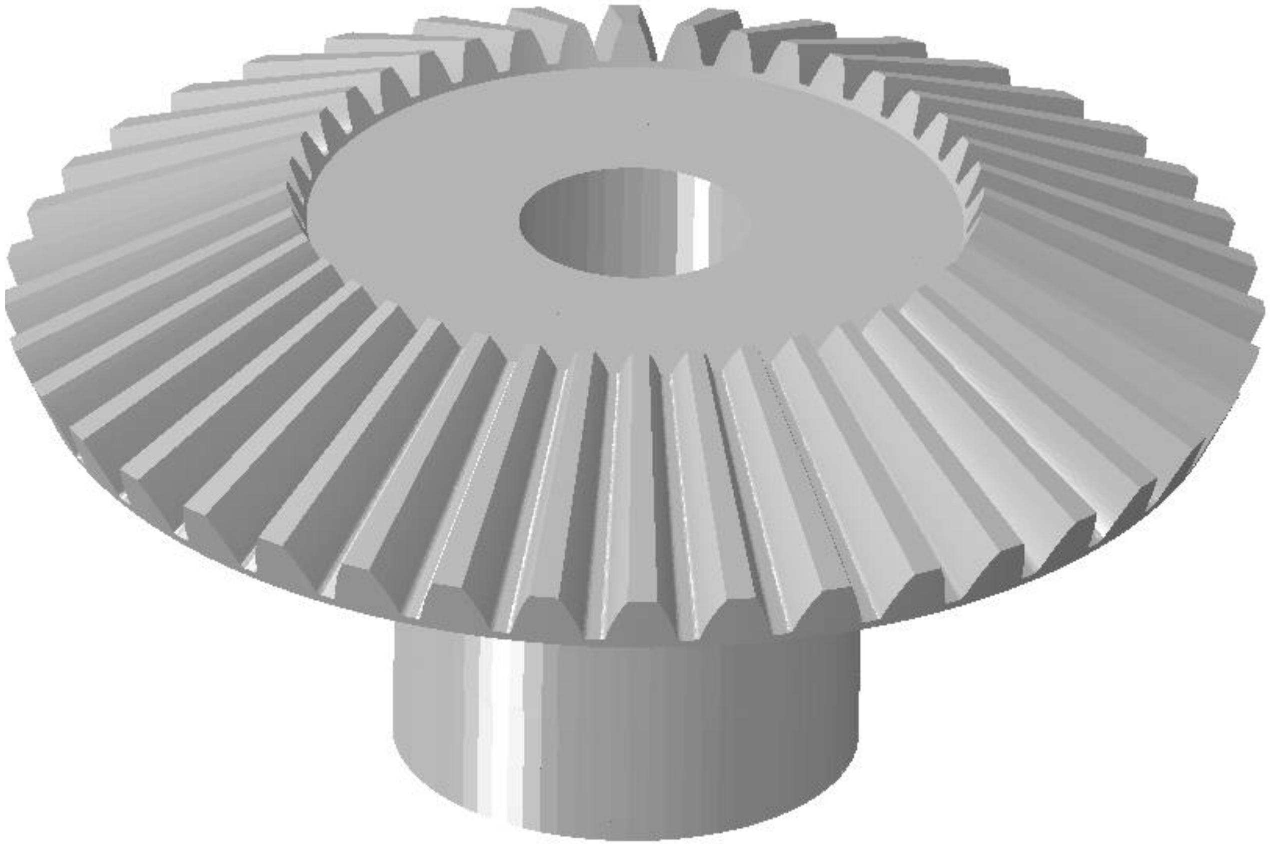


Bevel Gear Geometry

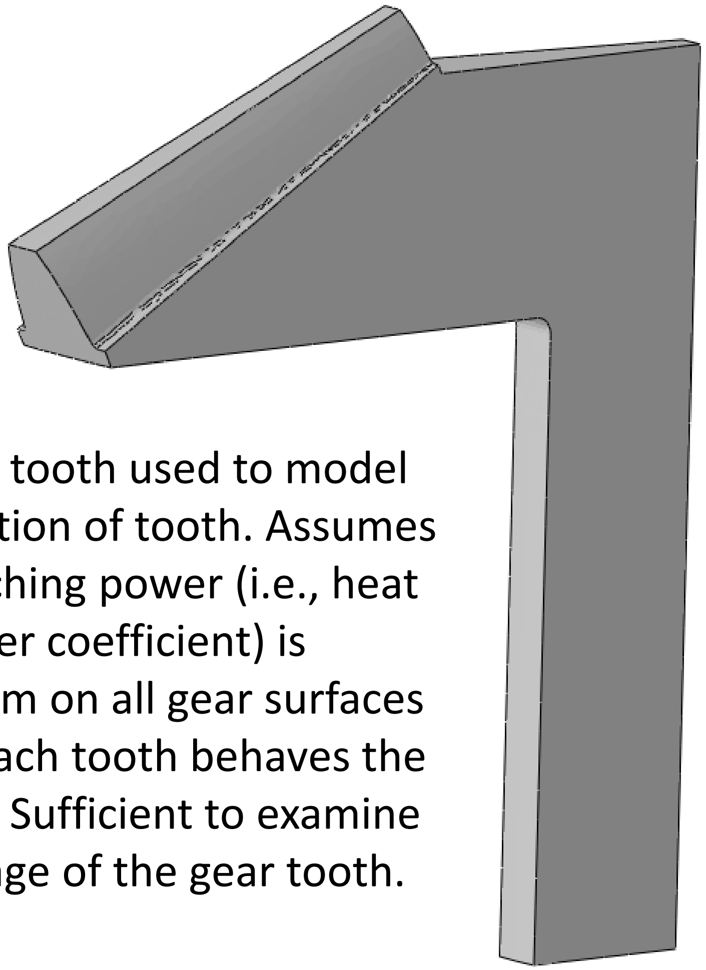
- Number of Teeth: 40
- Bore: 37.6 mm
- Outer Diameter: 205 mm
- Axial Length: 94.1 mm



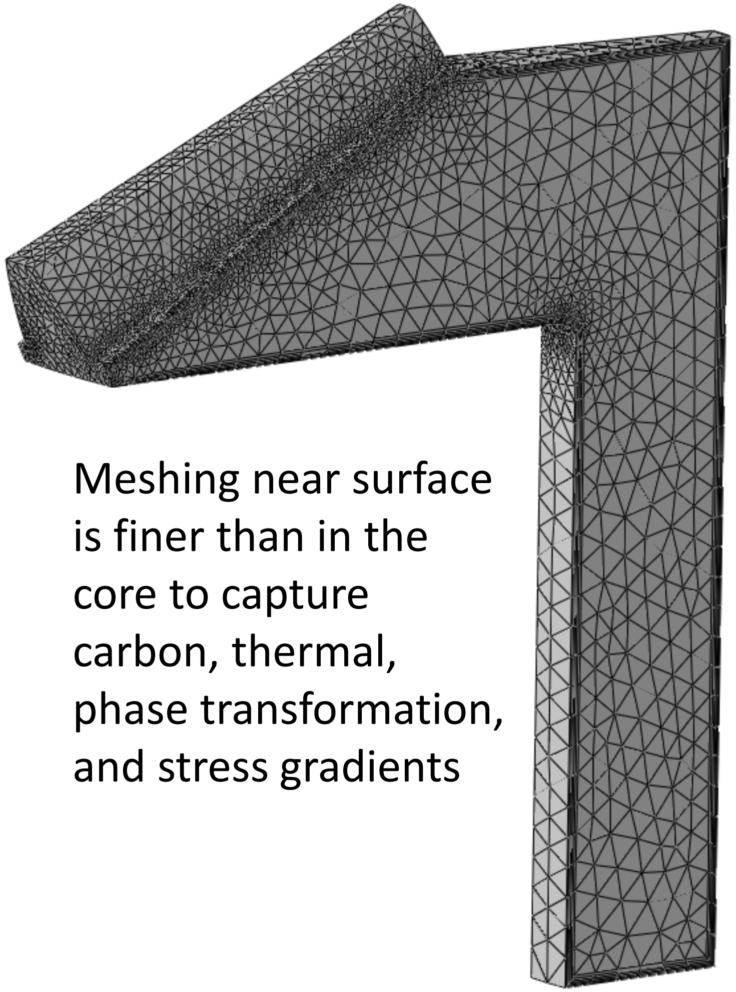




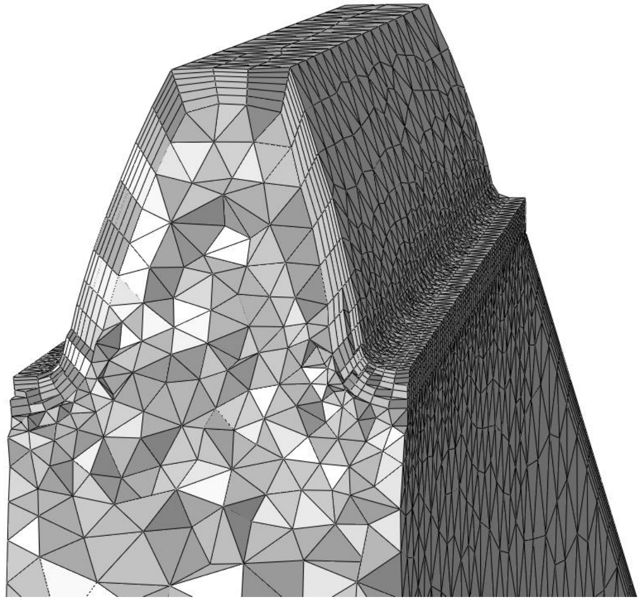
Model Description



Single tooth used to model distortion of tooth. Assumes quenching power (i.e., heat transfer coefficient) is uniform on all gear surfaces and each tooth behaves the same. Sufficient to examine warpage of the gear tooth.



Meshing near surface is finer than in the core to capture carbon, thermal, phase transformation, and stress gradients



Meshing inside tooth

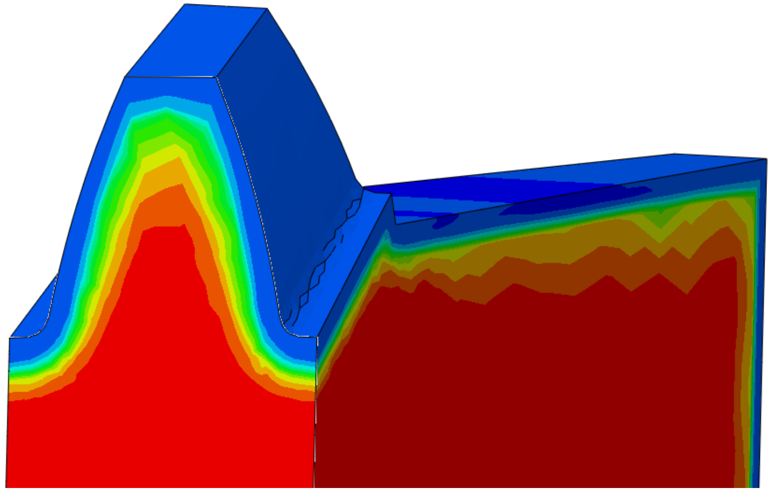
Single tooth CAD model

Single tooth finite element model

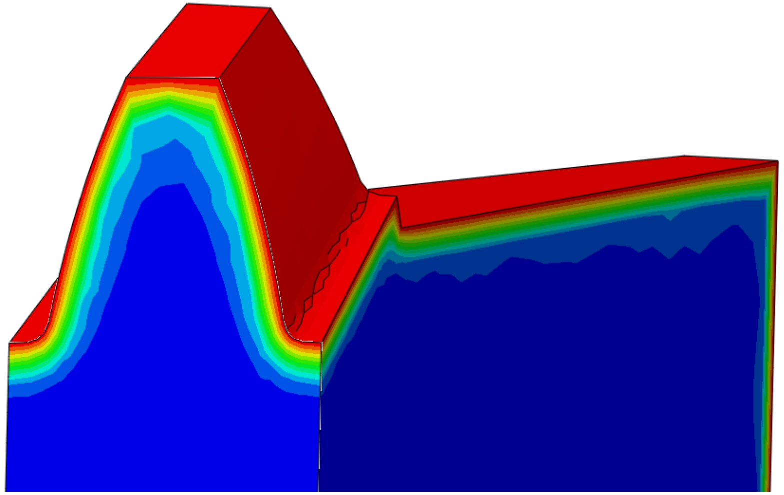
Process Description and Results

Process:

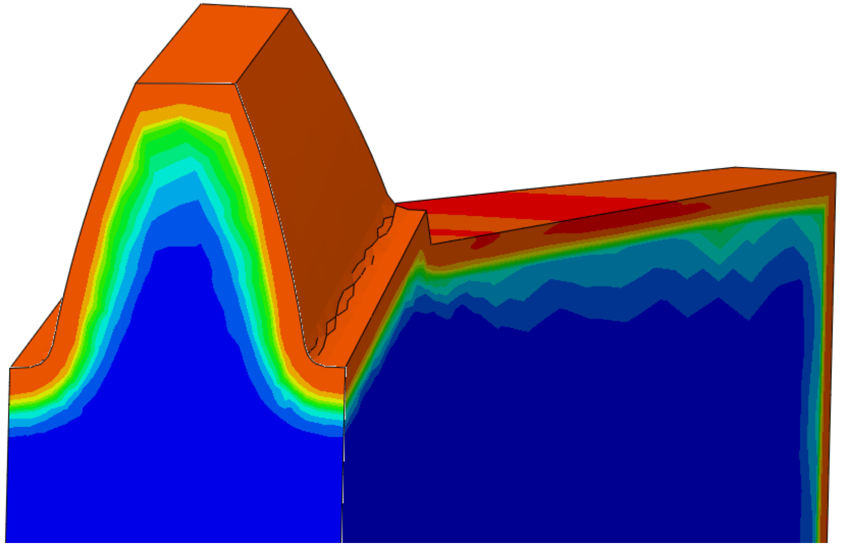
- Carburize
- Transfer to quench tank
- Quench in oil
- Cool to room temperature



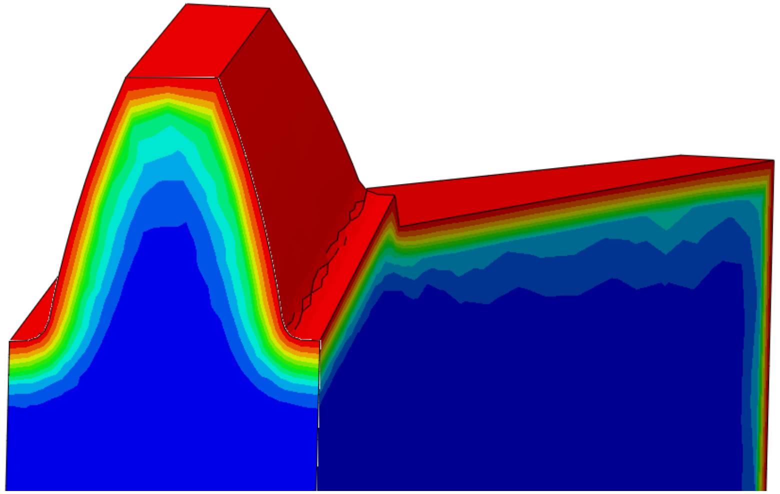
Martensite, Vol. Frac.



Carbon, Wt. Frac.



Retained Austenite, Vol. Frac.

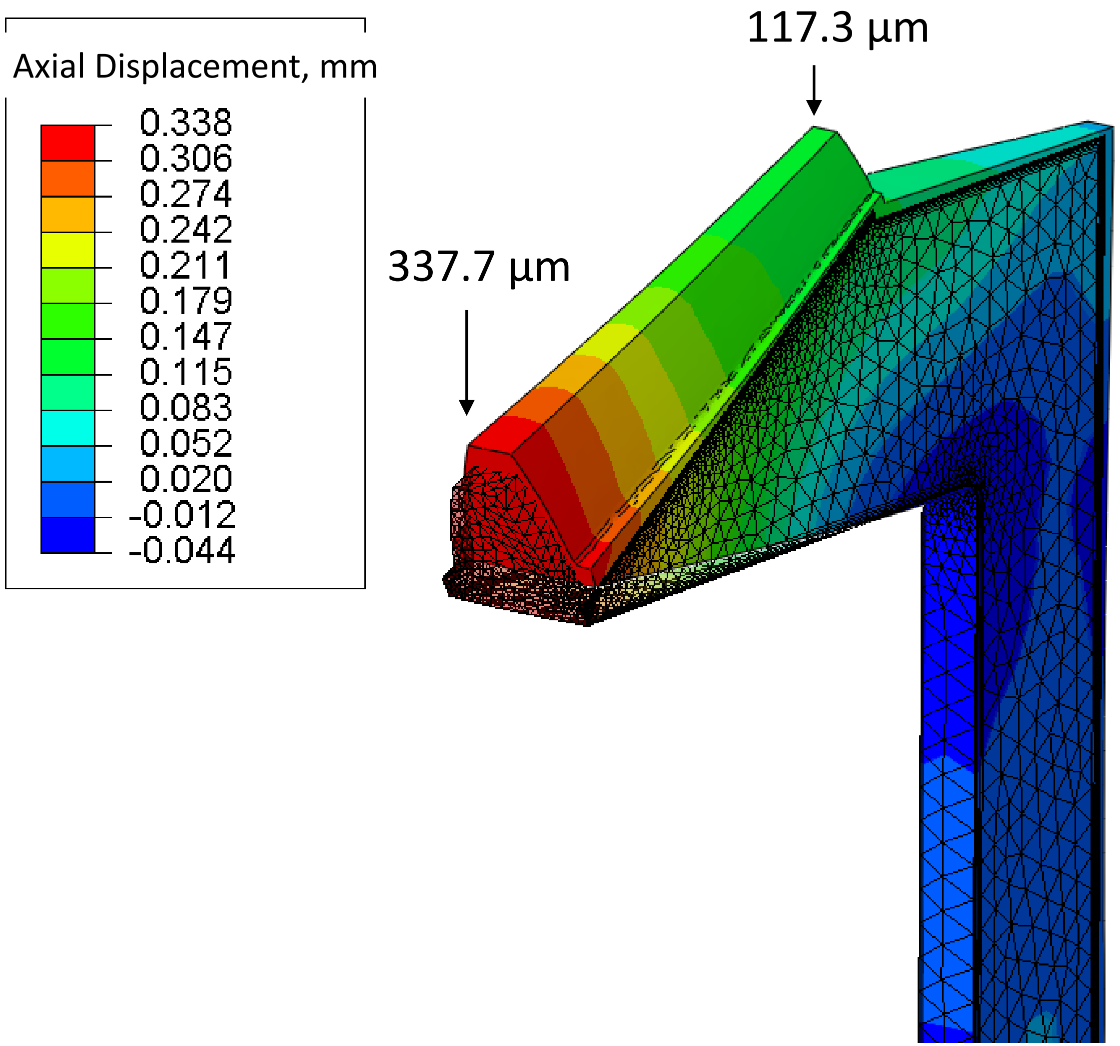


Hardness, HRC

Original Geometry and Process Distortion

Problem:

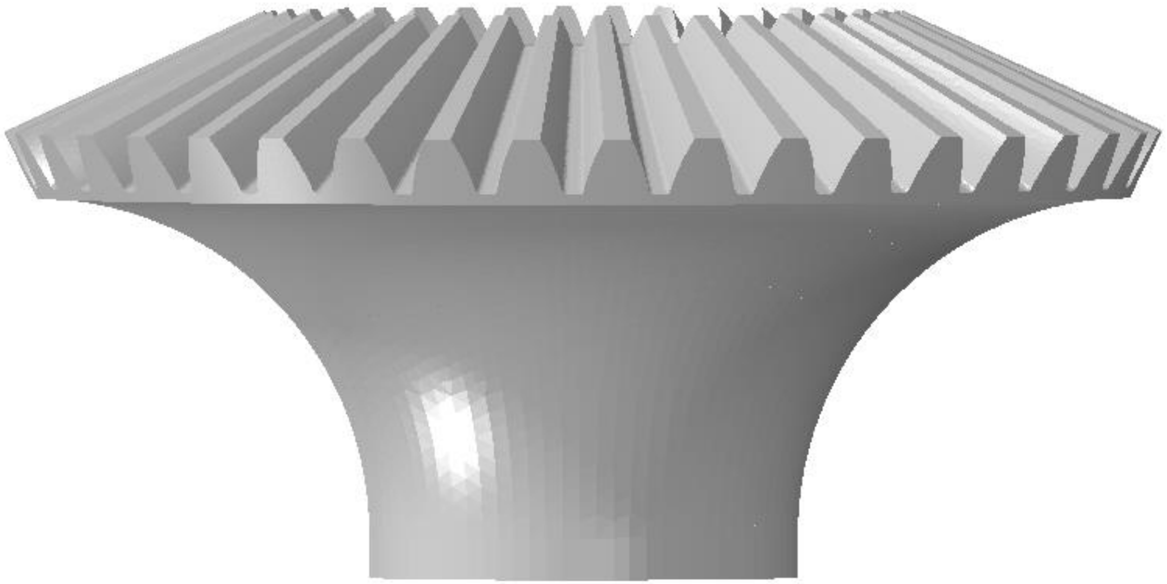
- Nonuniform and excessive distortion of the tooth in the axial direction during oil quenching
- Machining to correct distortion removes residual compressive stresses, damaging the fatigue performance
- Problem not discovered until after production began. Cost to correct at this stage is very high



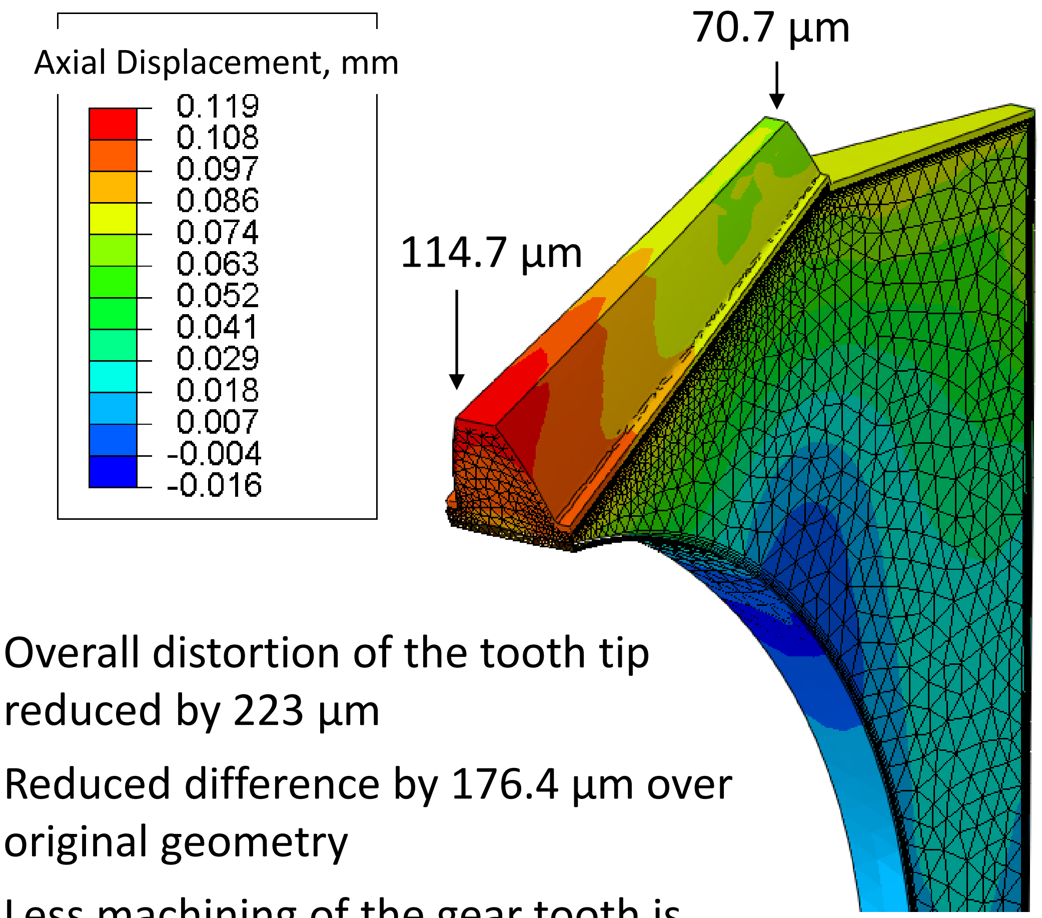
Solutions

- DANTE can be used as a troubleshooting tool, but using DANTE during the design stage to evaluate distortion during heat treatment is even more beneficial
  - Many problems resulting from heat treatment can be discovered and corrected before pre-production trials or production begins
  - Substantial cost savings can be realized by needing less trials to dial in the proper heat treatment schedule
- During the design stage, two paths to correct the distortion are possible:
  1. Change the geometry based on current process parameters to reduce distortion
     - Add material to the heat treat shape to increase stiffness of the gear tooth
     - Material can be removed after hardening if needed, but compressive stresses in tooth remain for enhanced fatigue performance
  2. Change the process based on the current geometry to reduce distortion
     - Use a process which offers better dimensional stability

Geometry Change



- New geometry added material to stiffen the gear tooth during quenching
- Material can be removed after hardening, if needed

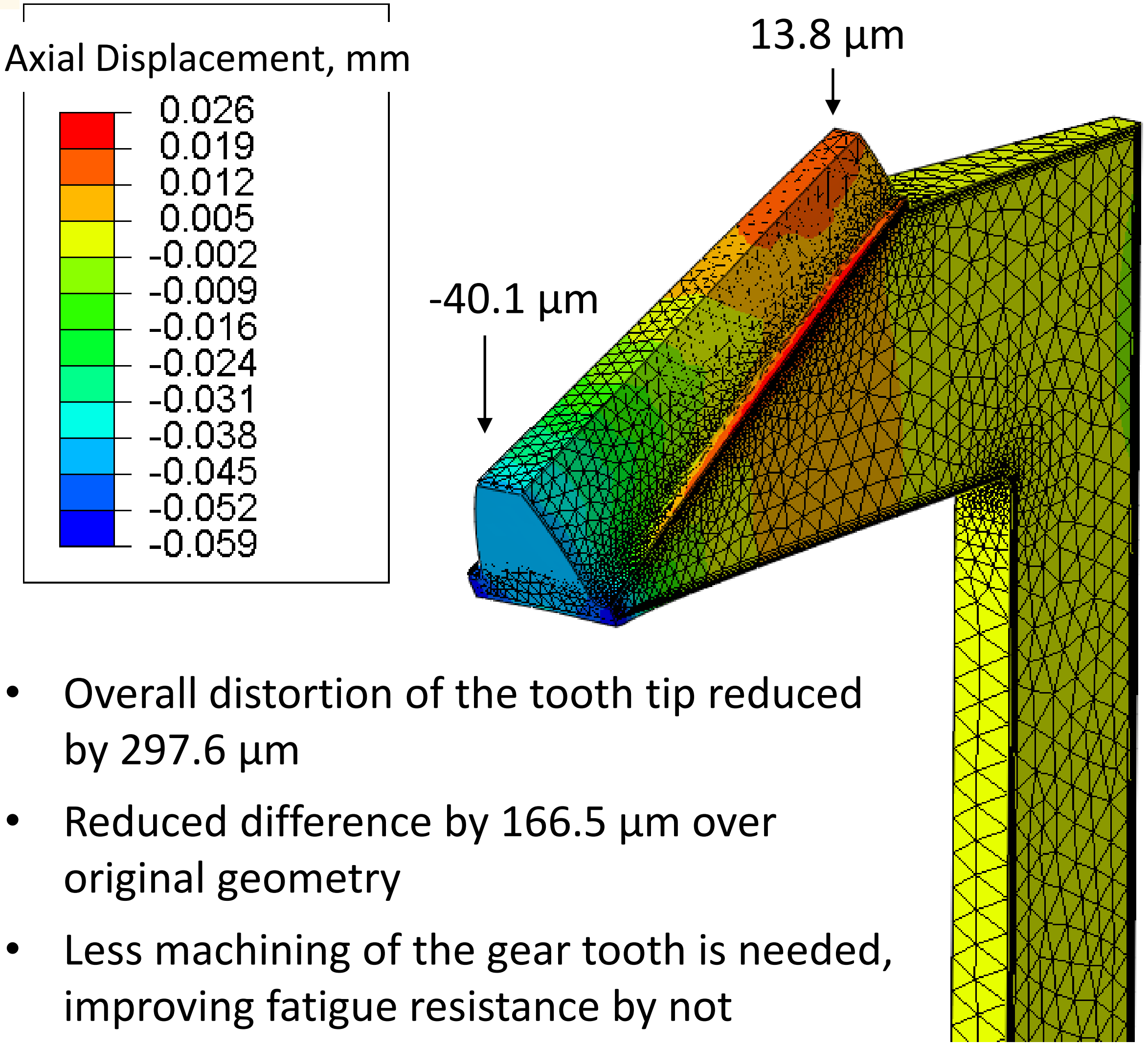


- Overall distortion of the tooth tip reduced by 223 µm
- Reduced difference by 176.4 µm over original geometry
- Less machining of the gear tooth is needed, improving fatigue resistance by not machining off the beneficial residual compressive stresses

Process Change

Process:

- Preheat part using induction heating
- Austenitize using induction heating
- Spray quench using a polymer solution
- Equivalent case depth was obtained compared to carburization/oil quench process



- Overall distortion of the tooth tip reduced by 297.6 µm
- Reduced difference by 166.5 µm over original geometry
- Less machining of the gear tooth is needed, improving fatigue resistance by not machining off the beneficial residual compressive stresses

Summary

- Difficult to quench bevel gear geometry showed excessive distortion of the gear tooth after a carburizing/ oil quenching process
  - Machining after the process to correct the distortion removed compressive stresses, damaging the fatigue performance
- DANTE was used to explore changes to correct the fatigue performance
  - Change the heat treat geometry to improve stiffness of the tooth
  - Change to a process with better dimensional stability (press quenching is also an option, which can be modeled with DANTE)
  - Cost savings can be realized if the analysis is done before pre-production trials or production begins