Steady State Thermal Finite Element Analysis of MK6+, MK7 and J-Head Extruders

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Overview

- Three types of 3D printer hot ends were analyzed using Thermal Steady State Finite Element Analysis
  - Makerbot MK6+
  - Makerbot MK7
  - Reprap J-head extruder

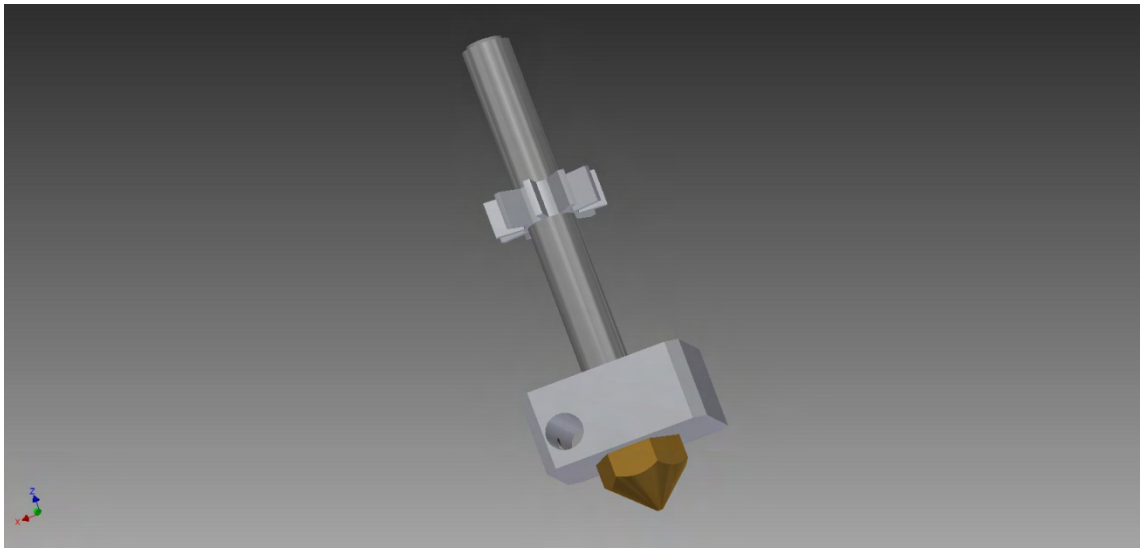
FEA Assumptions

- The following assumptions were used in the analysis:
  - Temperature is fixed at the thermal block surface corresponding to the heater hole
  - All other surfaces have convective loads at 25°C ambient
  - No ceramic insulation tape is assumed around the thermal blocks
  - PTFE tubing makes contact only with nozzle
  - No radiation effects or losses at threaded joints are considered.

Hot End Properties

Hot End	Mass (g, calculated)	Filament length (mm)
MK6+	38.9	84.95
Mk6+ w/PEEK Thermal Barrier	30.6	84.96
MK7	15.0	39.5
Mk7 w/PEEK Thermal Barrier	10.8	39.5
J-Head	26.2	57.5

Makerbot MK6+



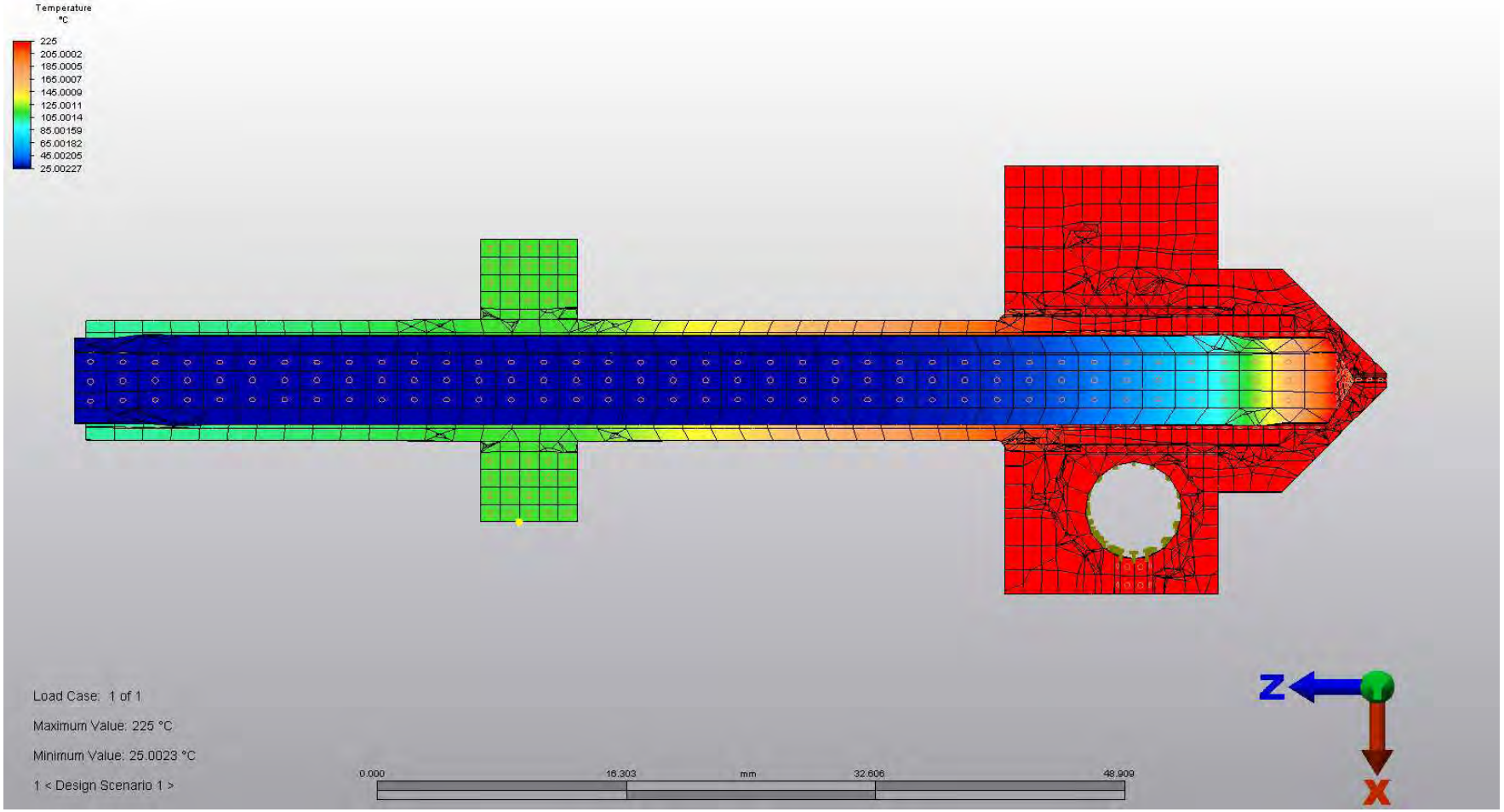
Modeled five components:

- •Brass nozzle
- •Aluminum 6061 thermal block and heatsink
- •Stainless Steel 303 thermal Barrier tube
- •PTFE tubing

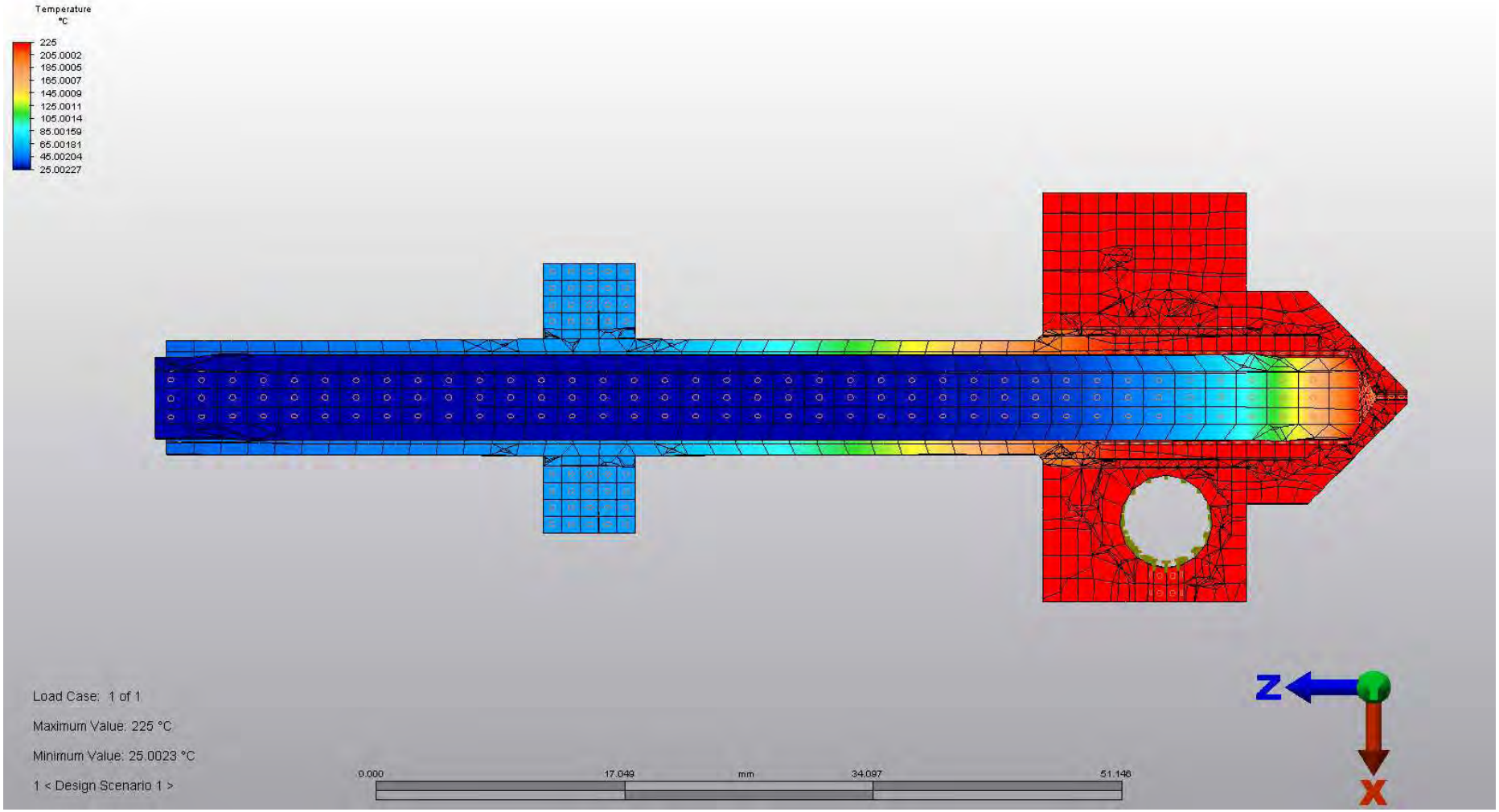
•Analysis was run with @ 225°C (25°C Ambient):

- •Case #1 As Designed no cooling
- •Case #2 As Designed with thermal barrier and heatsink active cooling
- •Case #3 As Designed without Heat sink and no cooling
- •Case #4 with PEEK Thermal Barrier and no Cooling
- •Case #5 with PEEK Thermal Barrier and Cooling
- •Case #6 with PEEK Thermal Barrier, no Cooling or PTFE tubing

MK6+ Case #1
As Designed No Cooling



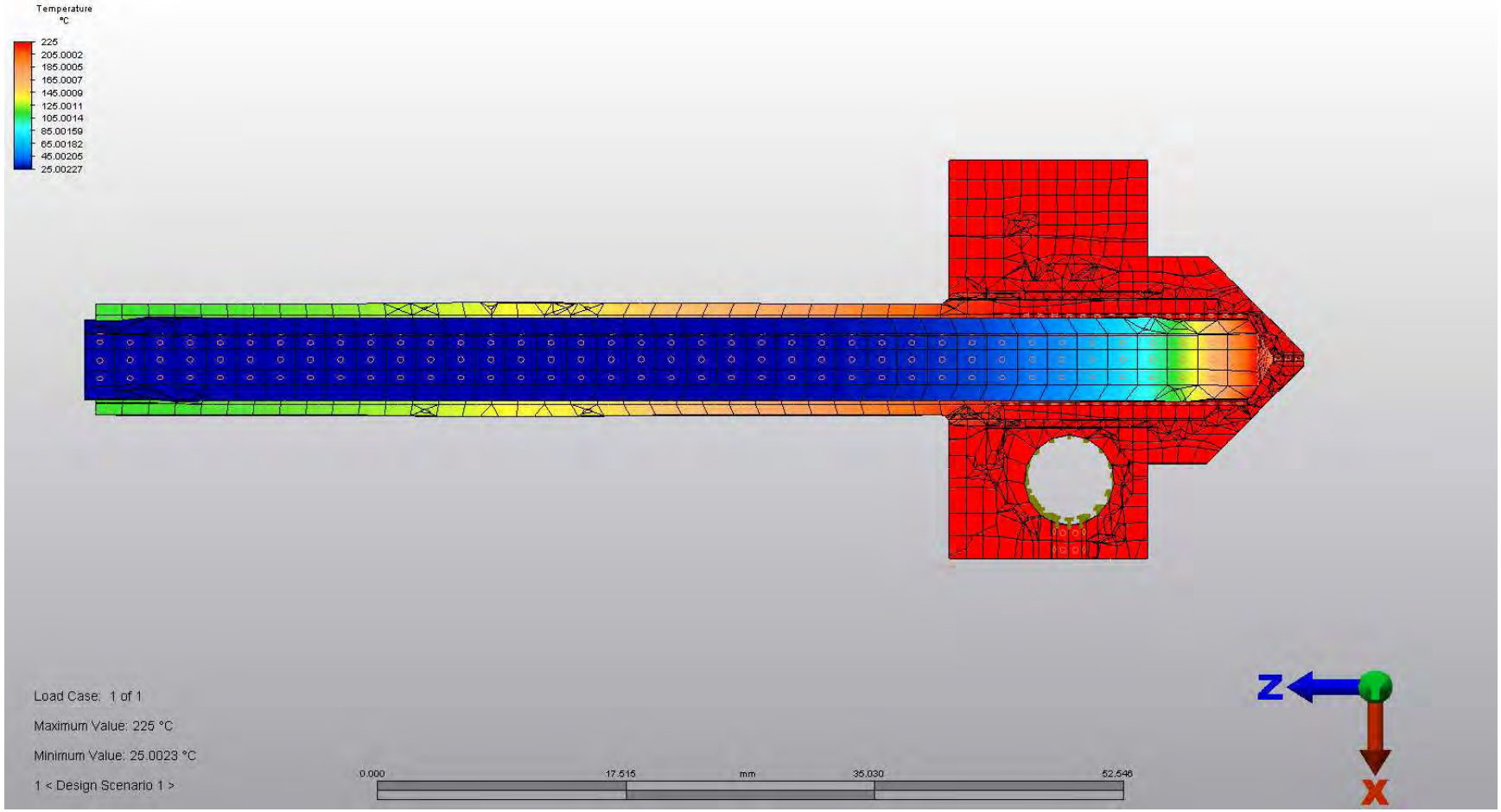
MK6+ Case #2
As Designed with Cooling on Thermal Barrier and Heatsink



Discussion

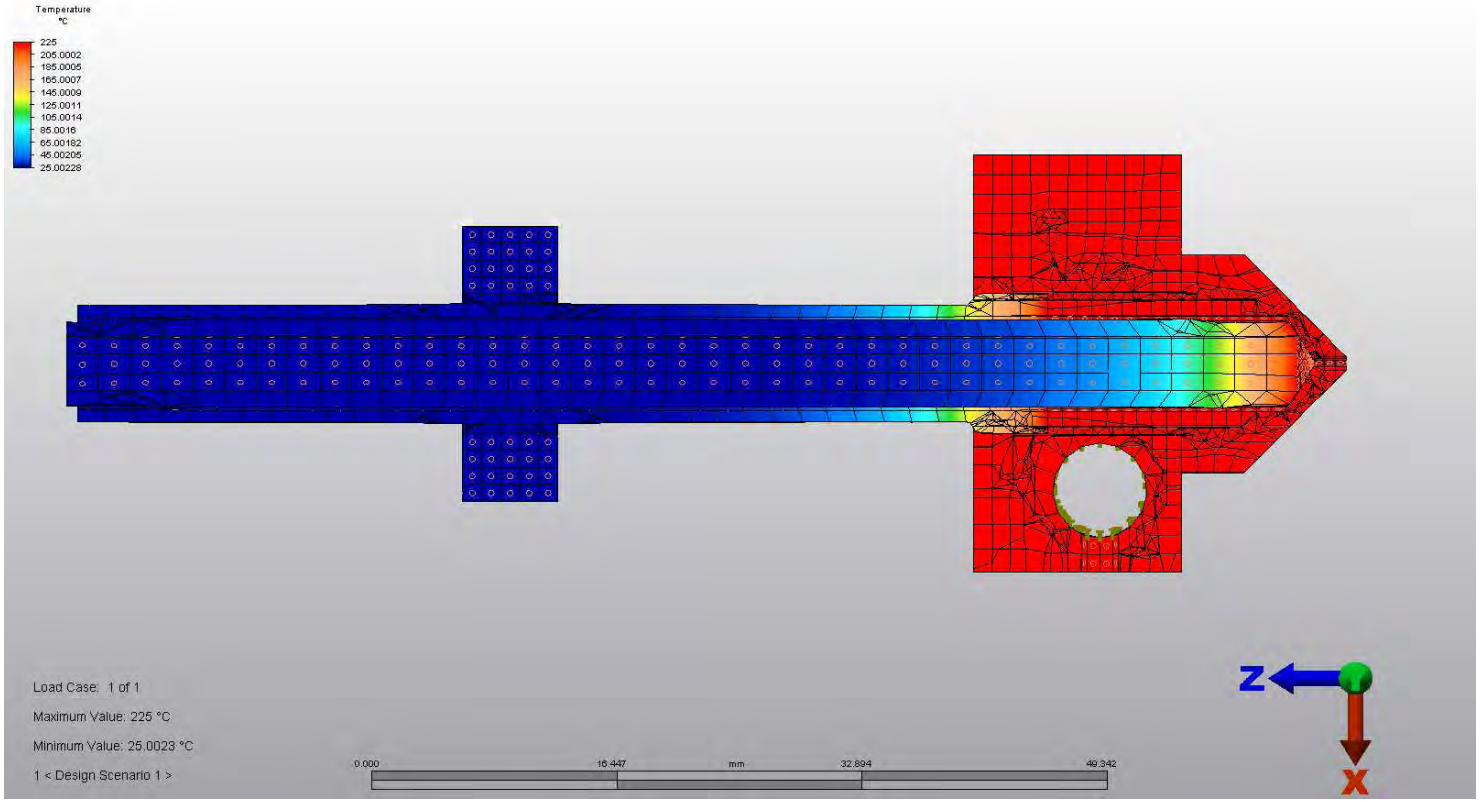
- Without cooling the temperature at the end of the thermal barrier tube is in the range of 125°C.
- With active cooling of the thermal barrier tube and heatsink the end of the tube is ~30-40°C
- The PTFE tube is largely showing at 25°C throughout its length. As modeled, the tube does not make contact with the walls of the thermal barrier.
- The PTFE tube provides considerable thermal insulation to the filament

MK6+ Case #3
As Designed No Cooling or Heatsink

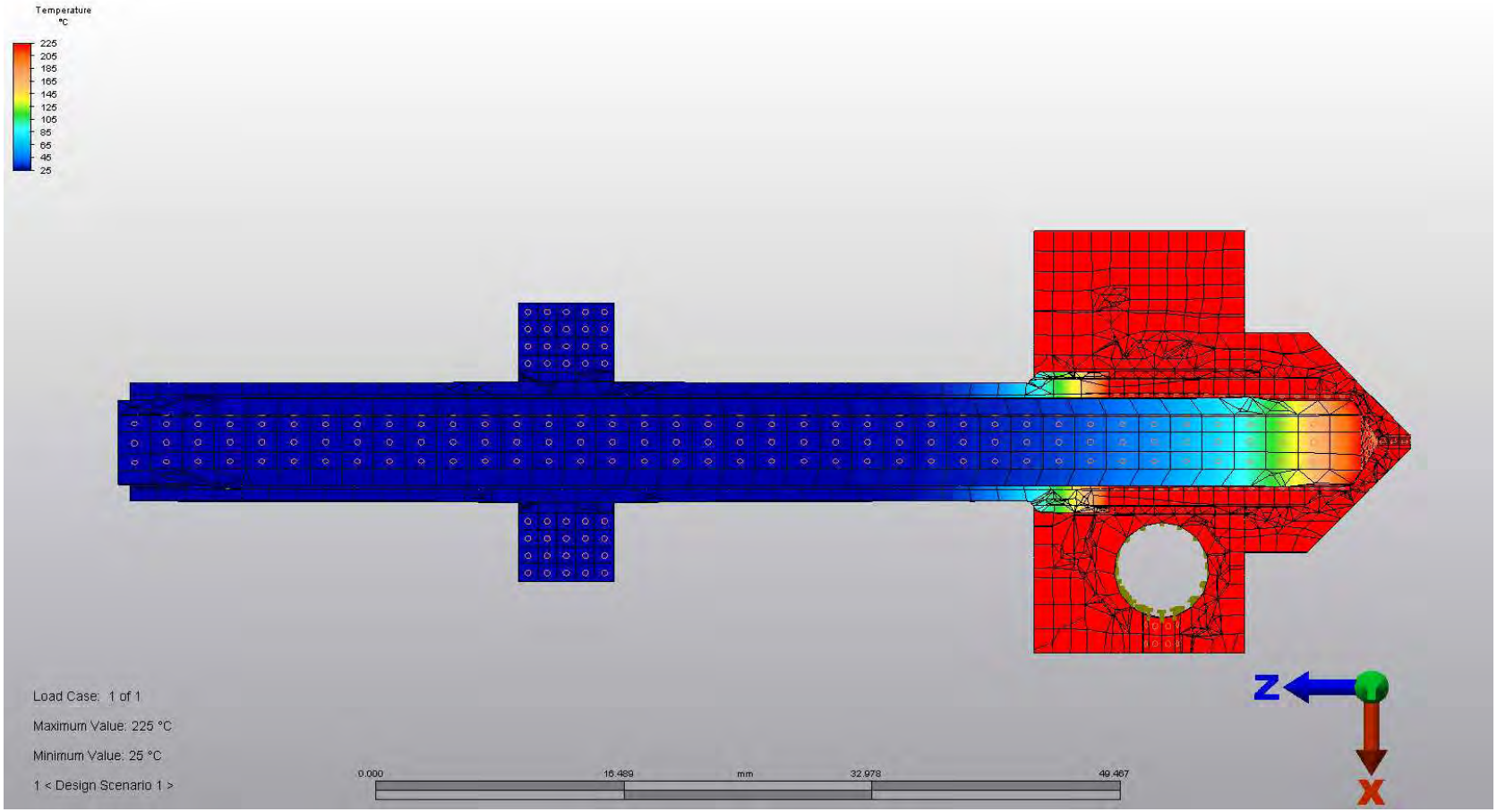


The Heatsink is effective in reducing the heated path length of the Thermal Barrier tube. However, the end of tube temperature remains largely the same.

MK6+ Case #4
PEEK Thermal Barrier and no Cooling



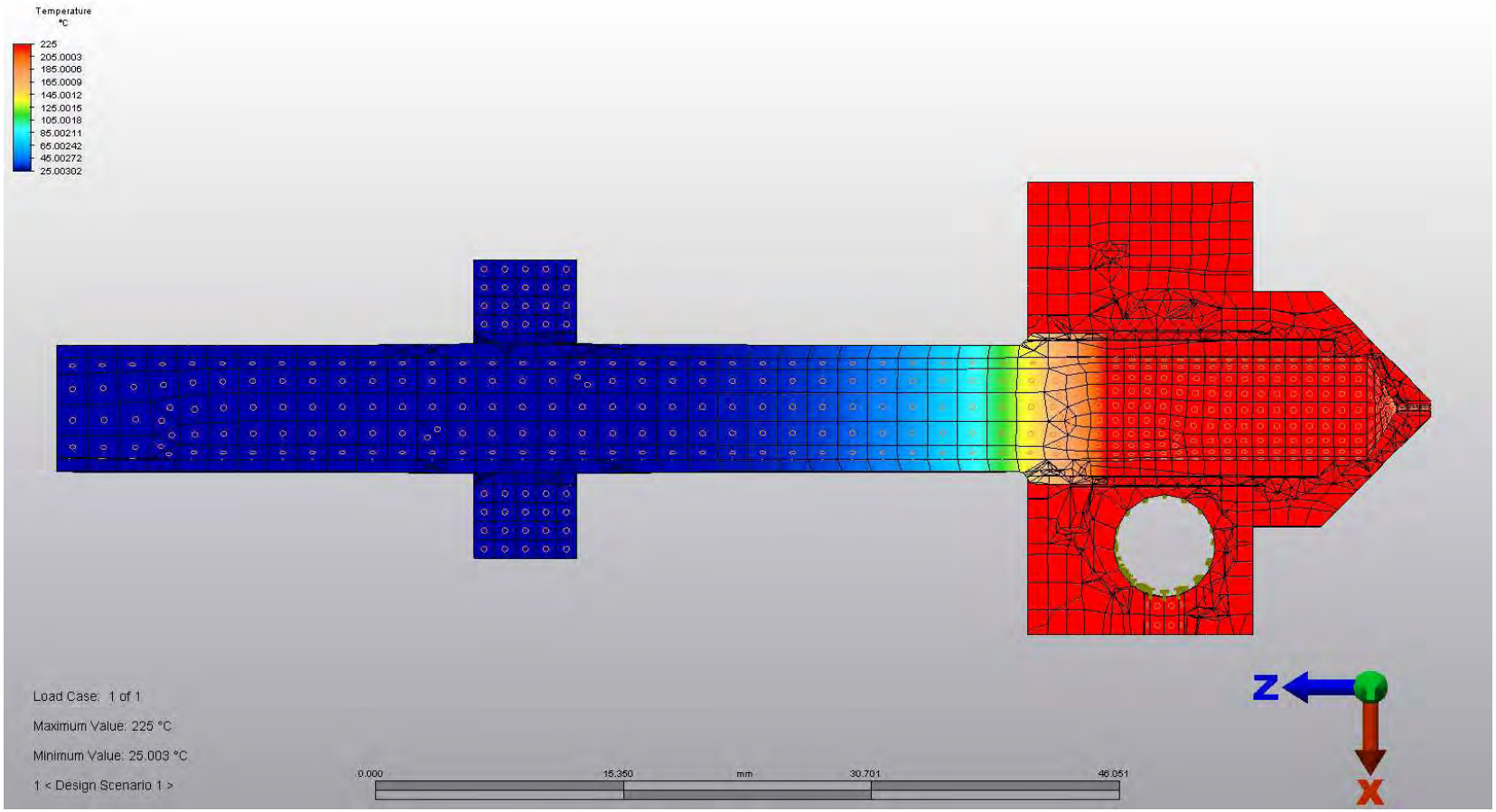
MK6+ Case #5
PEEK Thermal Barrier with Cooling



Discussion

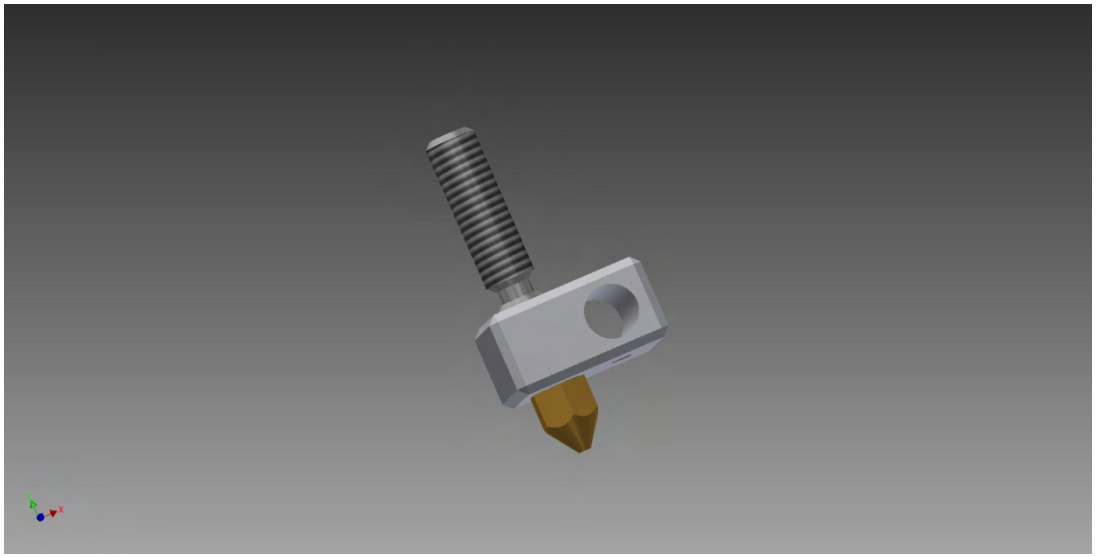
- All other things being equal (i.e., geometry etc) replacing the stainless steel thermal barrier tube with PEEK is highly effective at reducing the temperature of the tube to ambient along most of its exposed length.
- Active cooling further reduces the temperature.

MK6+ Case #6
PEEK Thermal Barrier No Cooling or PTFE



Melting temperatures remain confined to the thermal block and nozzle. Note that this case does not optimize the path of the filament and is therefore not realizable as a realistic option.

Makerbot MK7

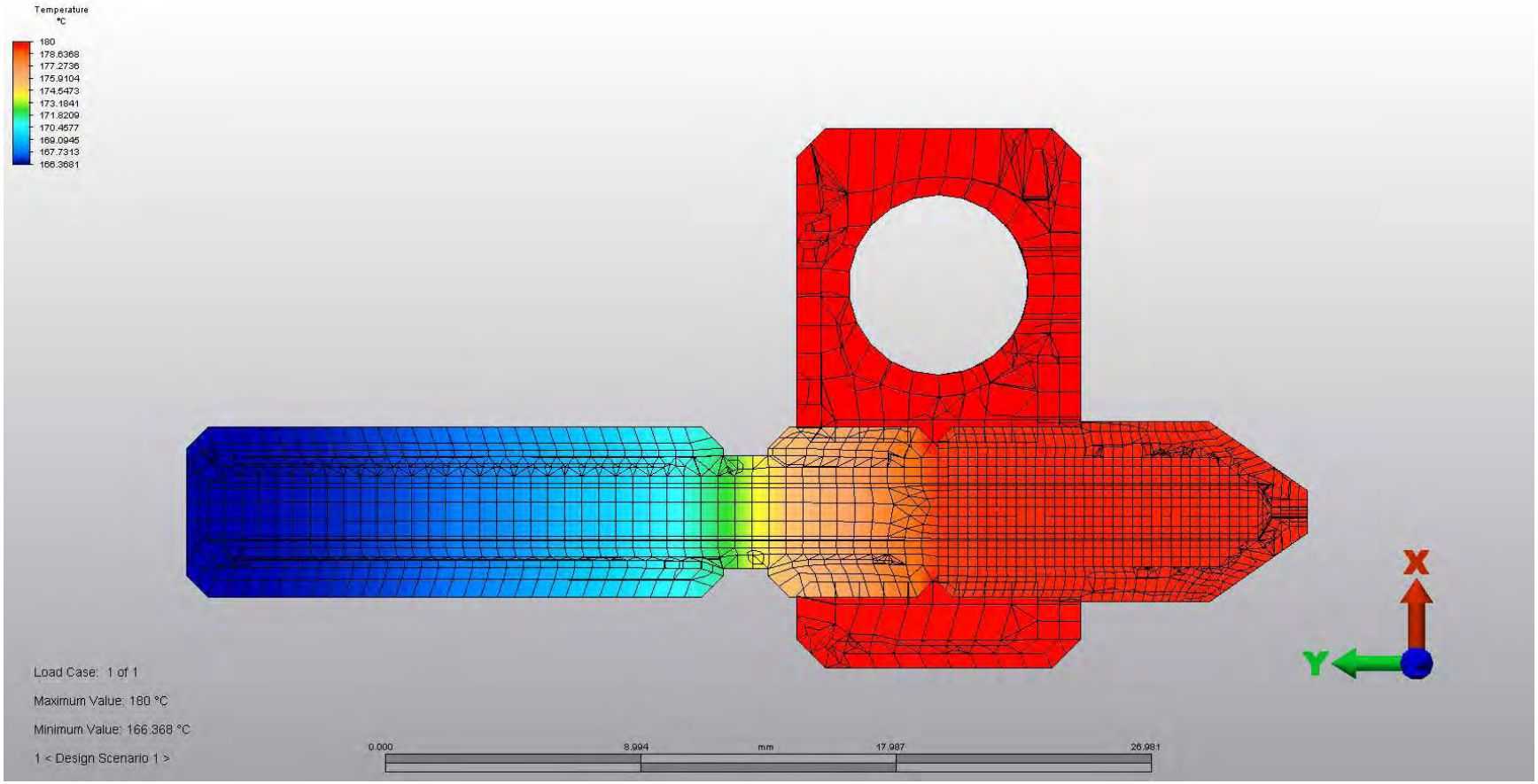


Modeled three components:

- Brass nozzle
- Aluminum 6061 thermal block
- Stainless Steel 303 thermal Barrier tube

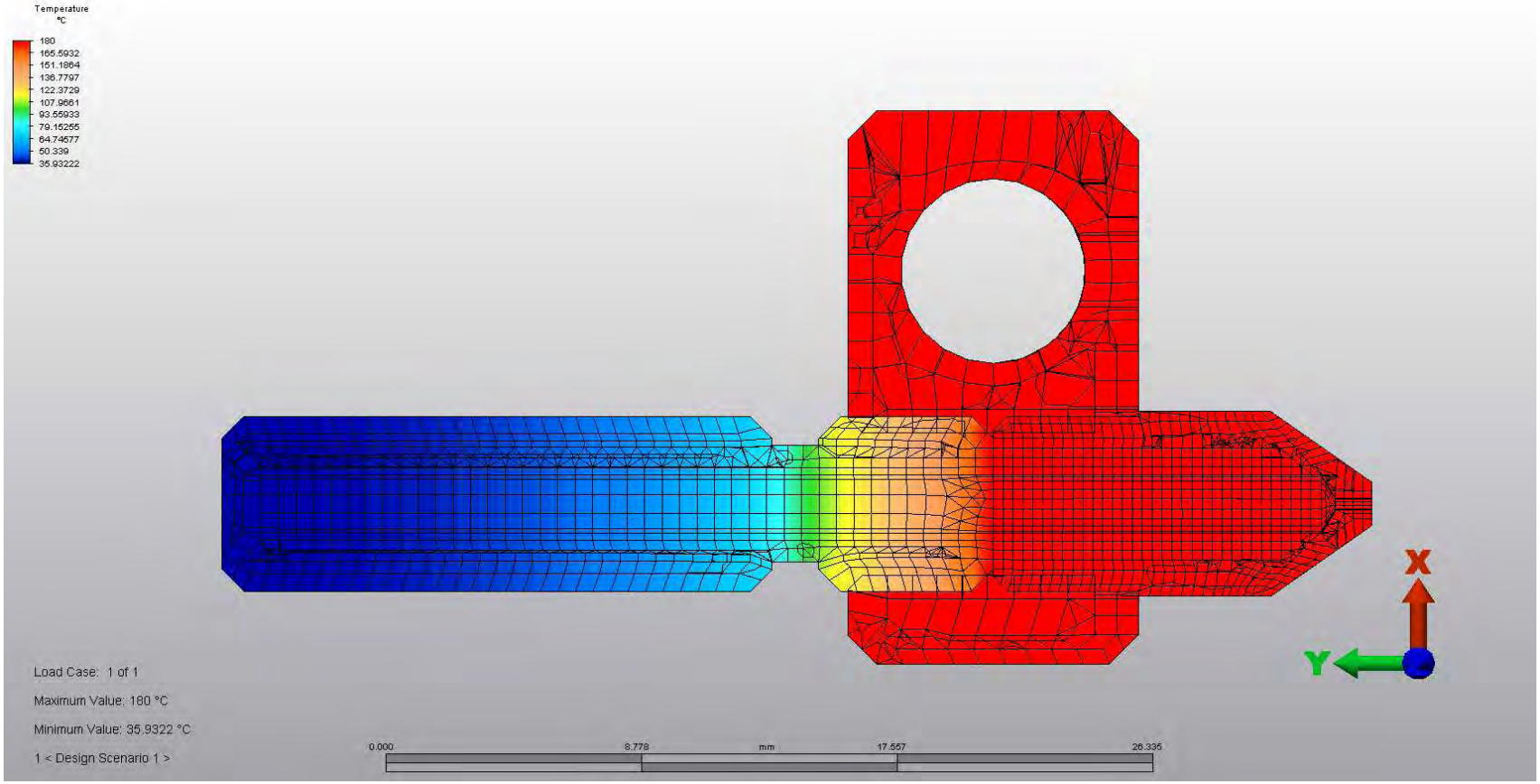
- Analysis was run with @ 180°C (25°C Ambient):
  - Case #1 As Designed no cooling
  - Case #2 with PEEK Thermal Barrier and no cooling

MK7 Case #1
As Designed No Cooling @ 180°C



The end of the thermal barrier tube is at 166°C. In practice there is additional heatsinking due to the motor mount. The constriction is effective in reducing the temperature beyond it. The overall path length is much shorter than the MK6+ or J-head extruders. This makes the end temperature problematic.

MK7 Case #2
with PEEK Thermal barrier No Cooling @ 180°C

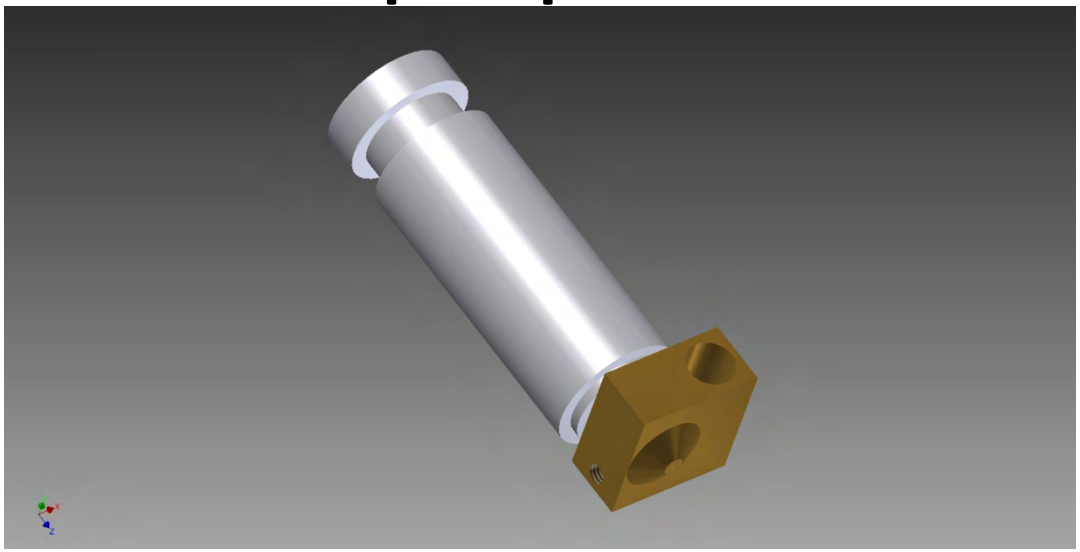


The end of the PEEK thermal barrier tube drops to 36°C. The heating length is significantly reduced and largely confined to the nozzle.

Discussion

- All other things being equal (i.e., geometry etc) replacing the stainless steel thermal barrier tube with PEEK is highly effective at reducing the temperature of the tube to ambient along most of its exposed length.
- Active cooling further reduces the temperature.

Reprap J-head



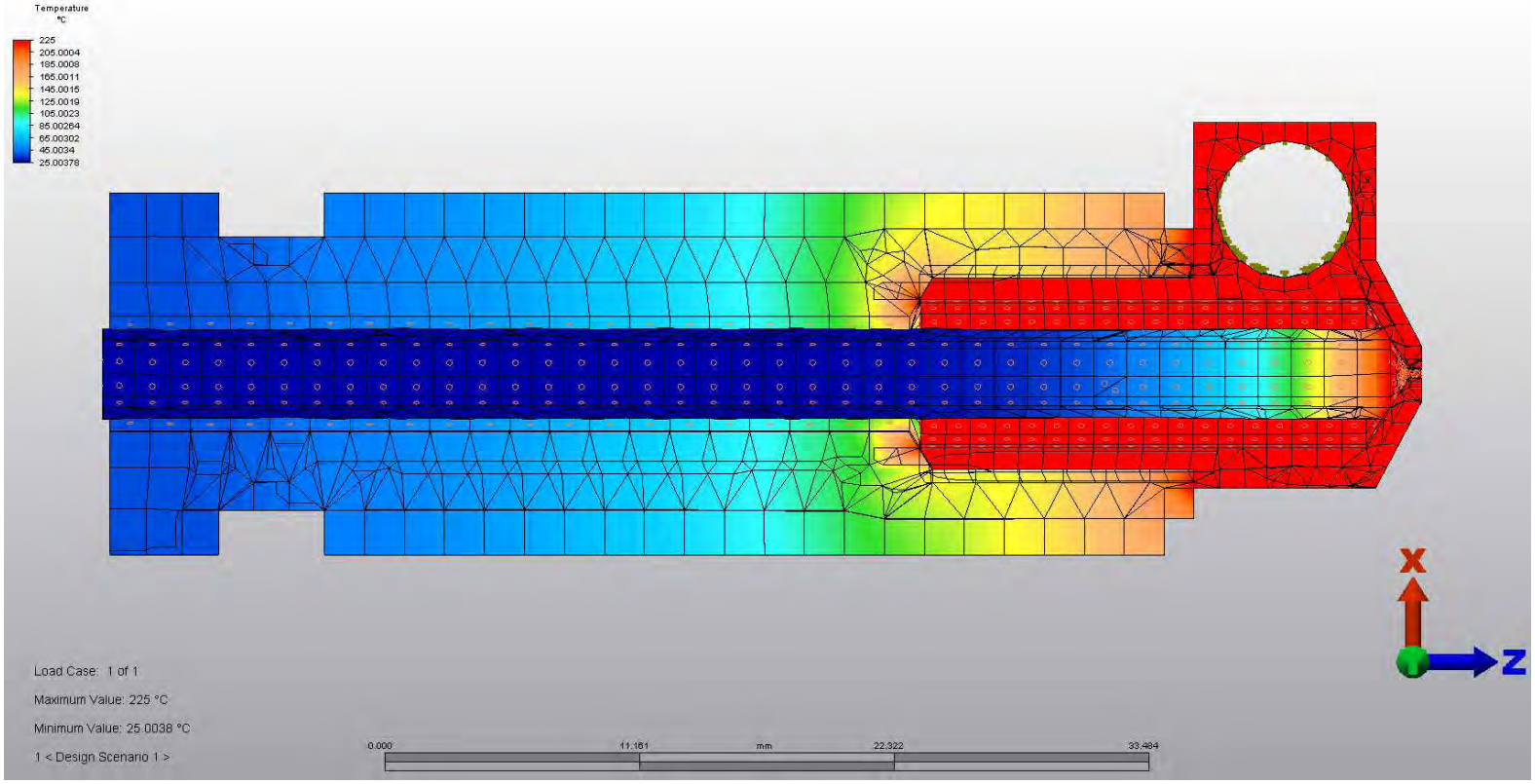
Modeled three components:

- •Brass nozzle and integrated thermal block
- •PEEK Thermal Barrier tube
- •PTFE tubing

•Analysis was run with @ 225°C (25°C Ambient):

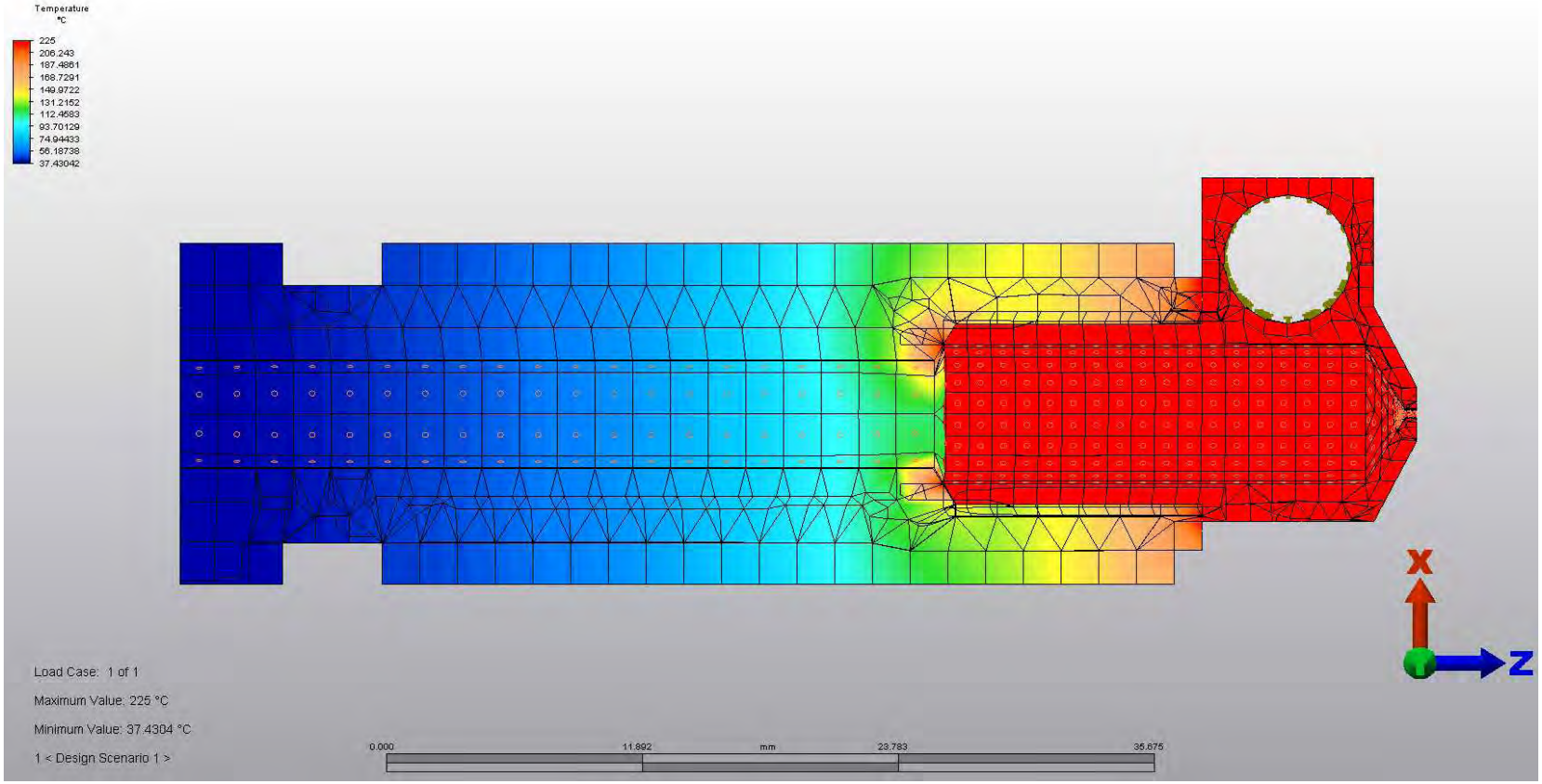
- •Case #1 As Designed no cooling
- •Case #2 without PTFE tubing

Reprap J-head Case #1
as Designed no cooling @ 225°C



The end of the thermal barrier tube drops to 36°C. The heating length is significantly reduced. PTFE tube helps insulate the filament along the length

Reprap J-head Case #2
as without PTFE Tube no cooling @ 225°C



Without the PTFE tube, the length the filament is exposed to melting temperatures is much higher. End of the PEEK Thermal barrier remains relatively cool.

Observations

- Nozzle and thermal blocks maintain fairly uniform heating throughout.
  - Reducing the melting area can be accomplished by reducing the threaded length of the nozzle and minimizing the length of the thermal block.
- PTFE tubing provides a good insulation path for filament and helps reduce exposure to high temperatures near the nozzle.
  - Secondary effect of controlling spreading of melted filament as it is approaching the nozzle orifice.
- Use of Stainless Steel for the thermal barrier tube is not optimum and still transmits significant heat to the cold end.
  - Not as significant on MK6+ as the path length is longer
  - Effect is significant with the MK7 as the thermal barrier tube is shorter and there is no PTFE tube to provide insulation.
  - Thermal Barrier tube length can be optimized and likely shortened
  - Replacing Stainless Steel with PEEK significantly reduces the temperature over the length of the thermal barrier.
    - Other materials can also be investigated
- Models have not been compared to actual readings. Relative comparisons between models are relevant as initial conditions and loads are unchanged.

Potential Improvements

- MK6+
  - Reduce the size of the nozzle and thermal block
  - Replace Stainless Steel Thermal Barrier tube with PEEK or other material with similar thermal and structural properties.
  - Reduce the length of the Thermal Barrier tube.
  - Active cooling does not appear necessary unless Stainless Steel continues to be used.
- MK7
  - Redesign to use PTFE tube and PEEK thermal barrier.
  - Further reduce size of the thermal block
- J-Head
  - Reduce length of threaded portion
  - Reduce overall path length
  - Potentially heat sink on end of thermal barrier over threaded area