ASM International Heat Treat Society

Short Time Dilatometry Quench System Analyses

By Andrew Banka, Andrew Senita of Airflow Sciences Corporation
By Robert Goldstein, Tareq Eddir of Fluxtrol, Inc.
By Robert Cryderman of Colorado School of Mines

Overview

- Effect of Short Time Heat Treatment on Transformation Phenomena
- Dilatometer Description
- Previous dilatometer cooling system simulations
- Development of alternate cooling options
- Impact of modified system on induction heating
- Full cooling simulation and comparisons
- Conclusions

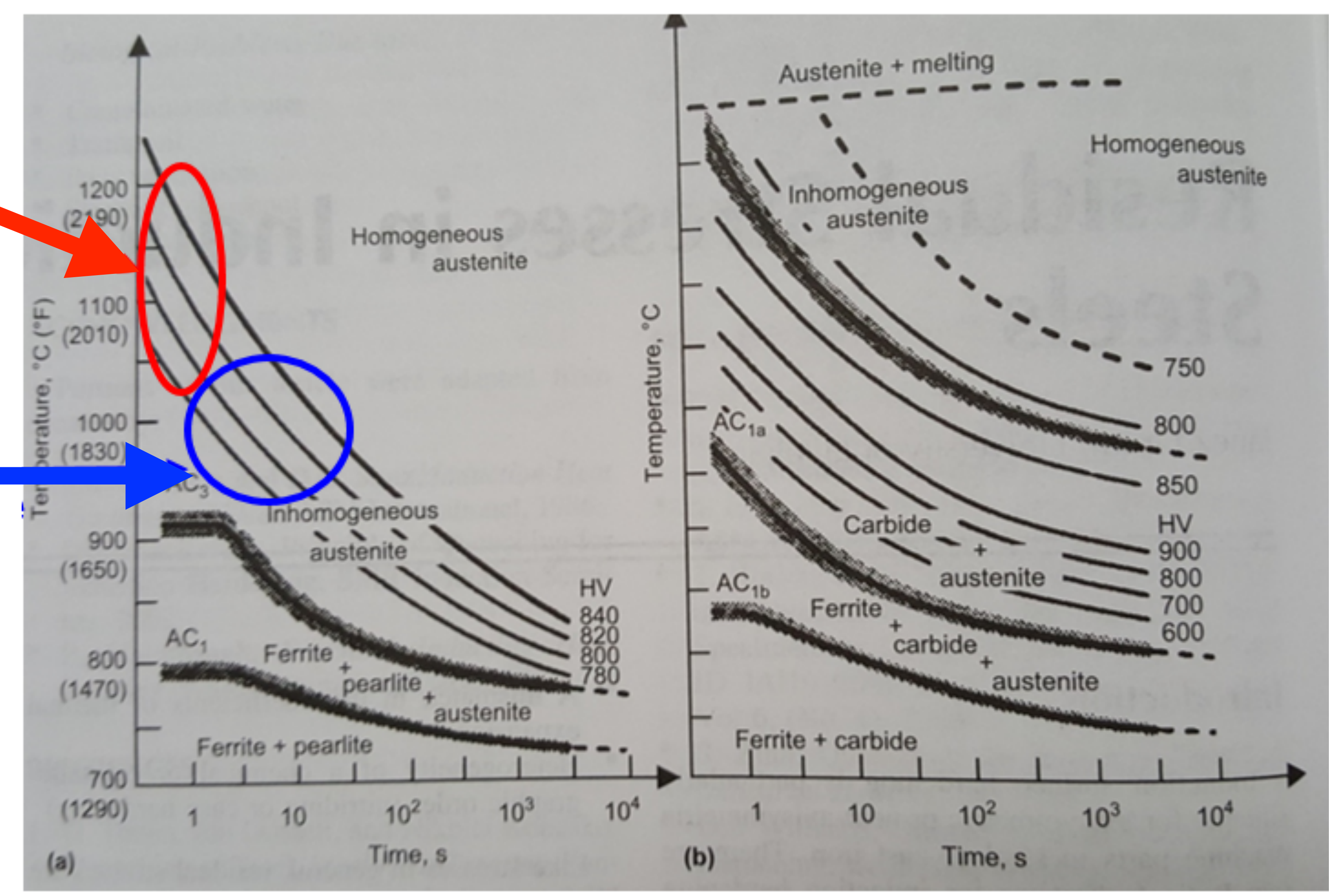
Effect of Short Time Heat Treatment on Transformation Temperature

Superior Performance of Components Has Been Achieved in Many Cases Using Non-Equilibrium Thermal Processes (NETP), but There Is Very Little Quantitative Data Available on Material Response to Rapid Thermal Processing

.

Hypoeutectoid
Creating Homogeneous Austenite in this range, create Flash Bainite® Structure, good elongation, reasonable hardness

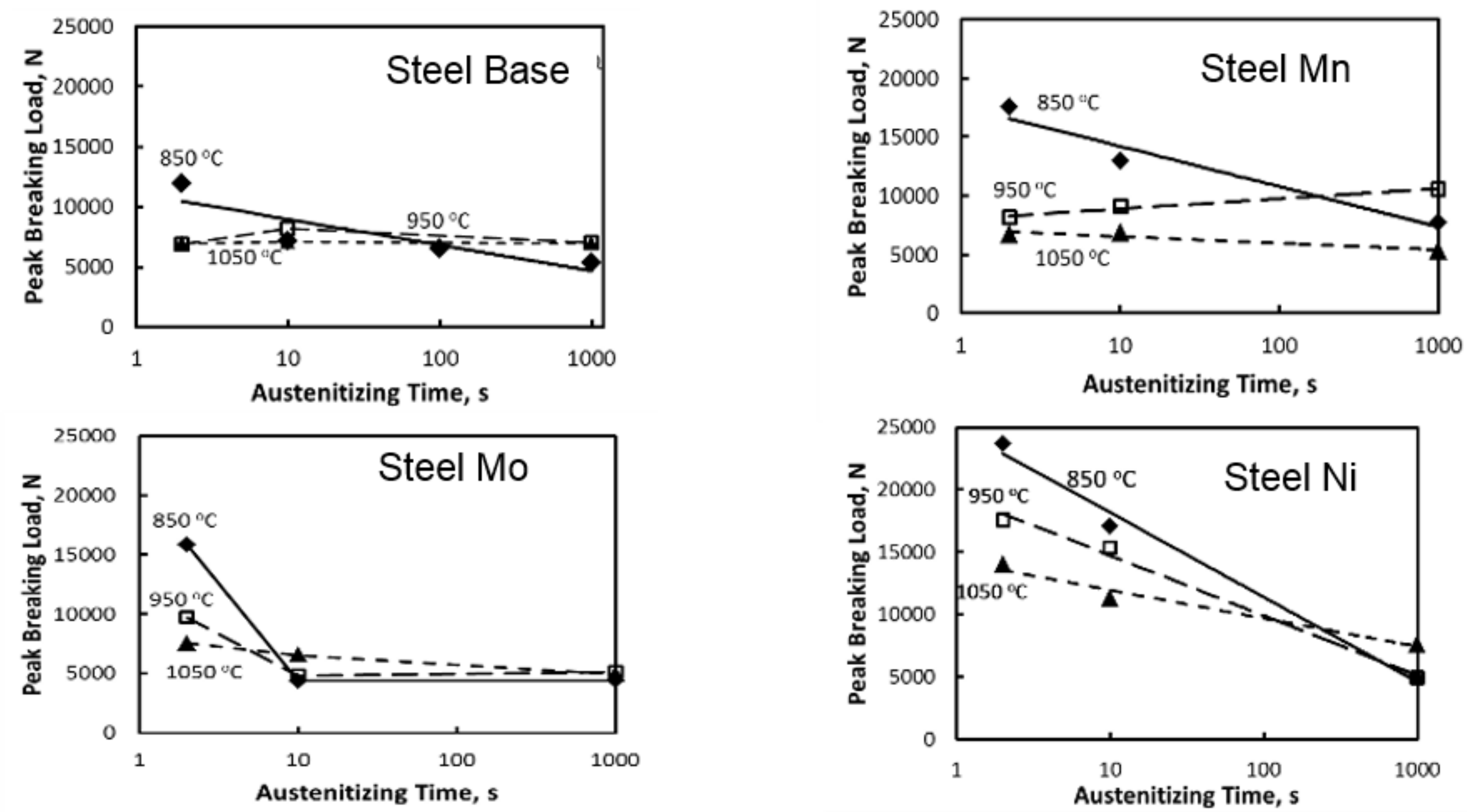
Creating Non-Homogeneous Austenite in this range common in industry and is part of near surface structure of many induction heat treated components and creates good hardness



Hypoeutectoid steel Ck45 left, Hypoeutectoid steel 100Cr6 right
Source - ASM Handbook Volume 4C - Grum

Recent Findings at ASPPRC of Improved Mechanical Properties with NETP

Up to 3X better properties demonstrated using appropriate alloying elements and relatively short, low temperature heat treatment



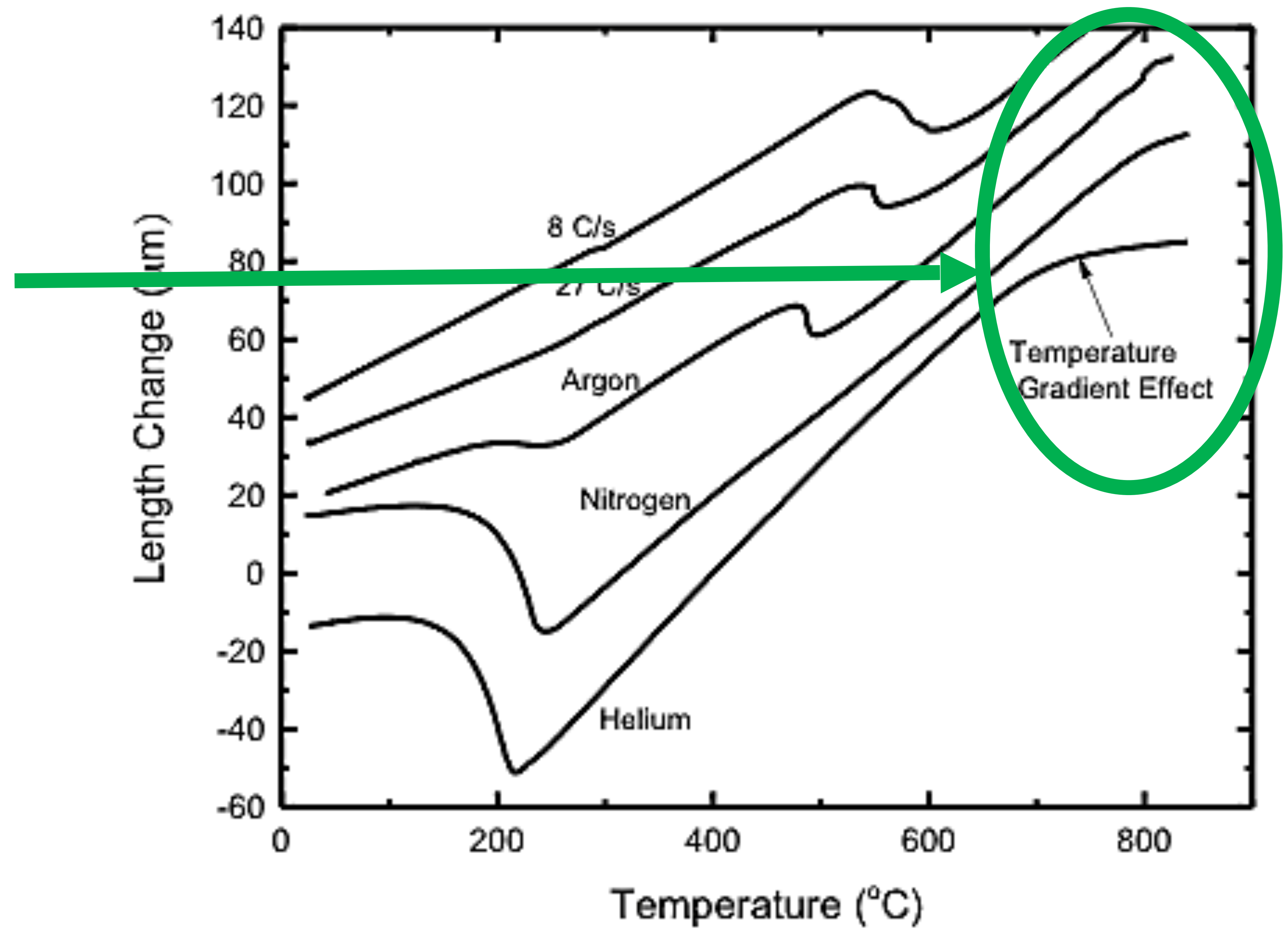
Microstructure and Notched Fracture Resistance of 0.56% C Steels After Simulated Induction Hardening

Robert Cryderman and John Speer
Advanced Steel Processing and Product Research Center, Colorado School of Mines, Golden, Colorado, 80401, USA,
rcryderm@mines.edu

Corrosion Prevention for SMC's

Effect of Reduced Pre-Transformation Expansion with Increasing Cooling Rate called Temperature Gradient Effect and Led to Impression There Was Non-Uniform Temperature in the Sample

Cooling Rates:
He: 235 ˚C/s
N: 91 ˚C/s
Ar: 52 ˚C/s

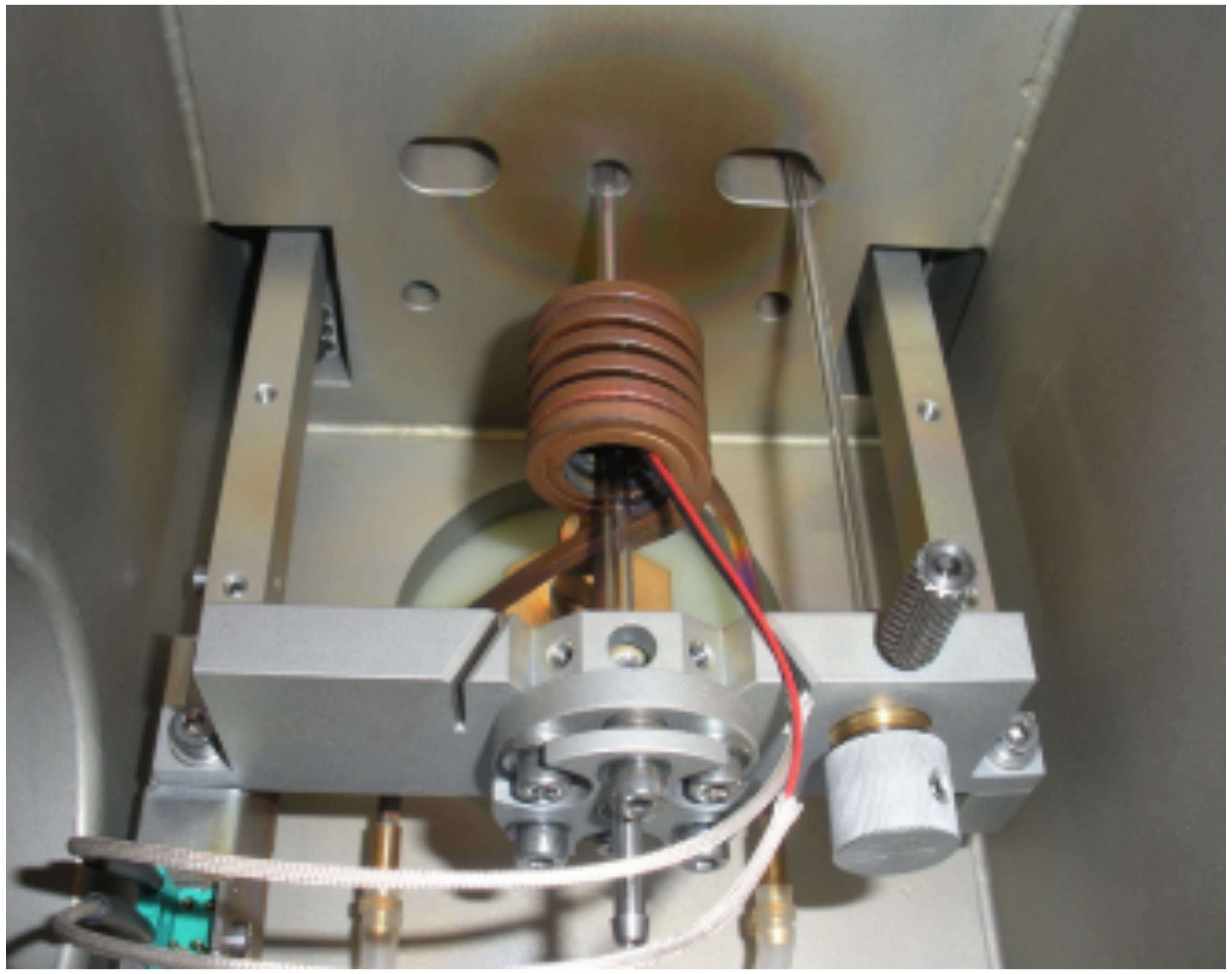


Short Time Austenitizing Effects on the Hardenability of Some 0.55 wt. pct. Carbon Steels

Robert Cryderman and Trevor Ballard

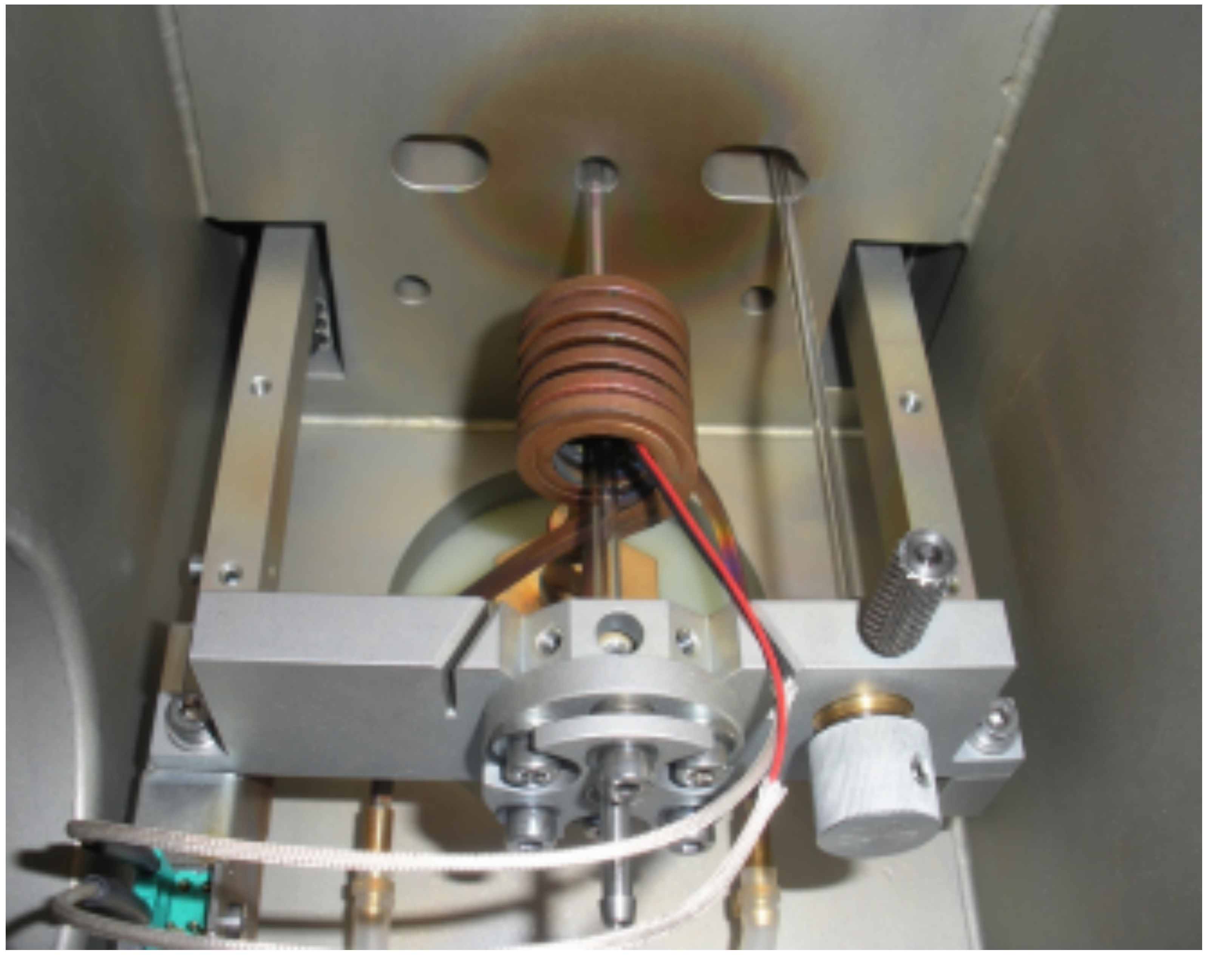
Dilatometer Description

- Measures dimensional movement during thermal procession
- Heating is in a vacuum
- Heat source is induction heating
- Advertised heating rate up to 1000 C/s
- Gas quenching through second coil inside induction coil
- Fused silica tubes hold the component
- Manufacturer TA Instruments



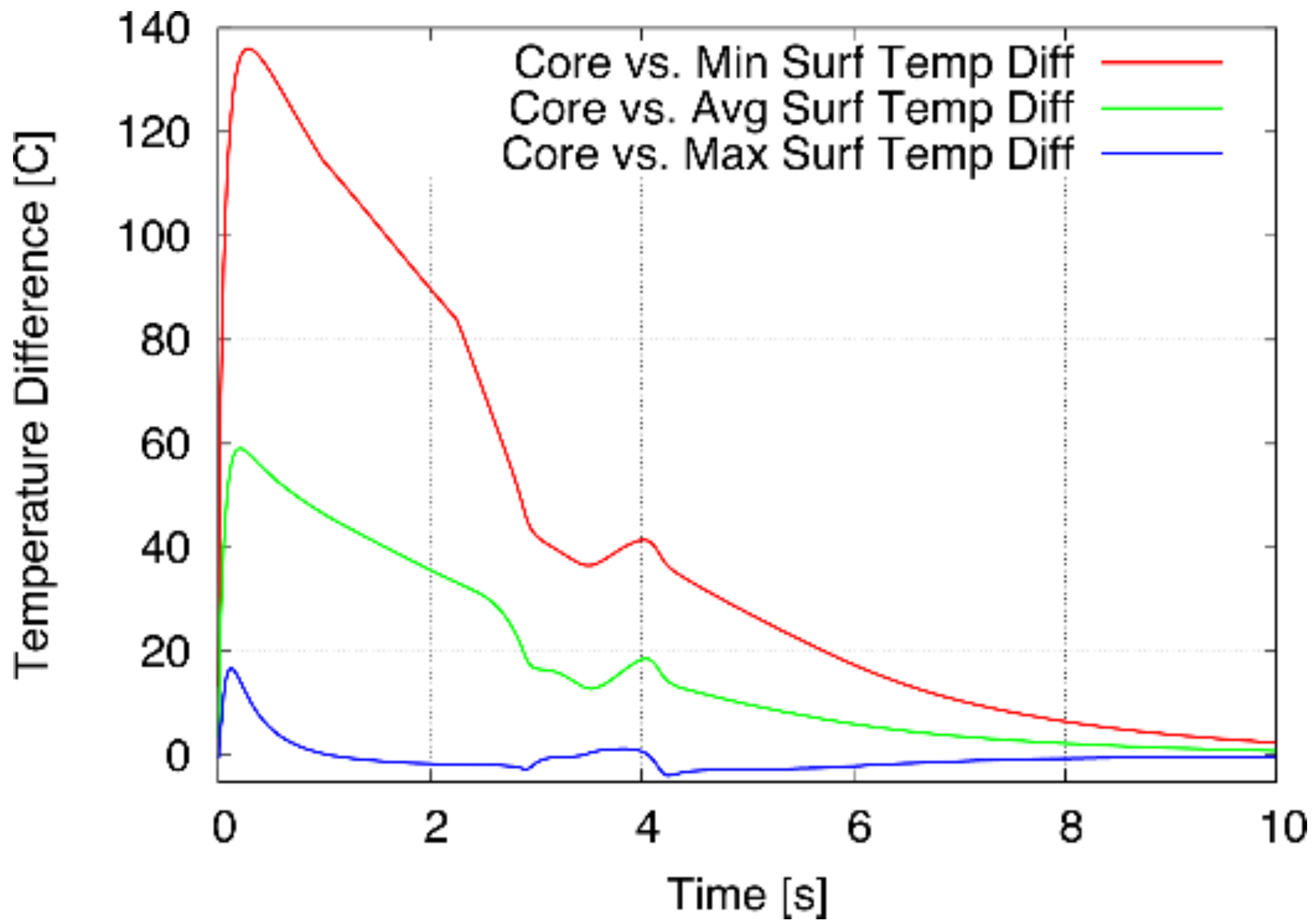
Previous Testing/Analysis Results

- Initially, sample temperature monitored at one location at the sample surface center
- TCs added at both ends showed significant temperature differences during cooling (but not heating)
- CFD analysis of existing helical coil quench confirmed variation in cooling
- Goal of current study is to develop an improved cooling method

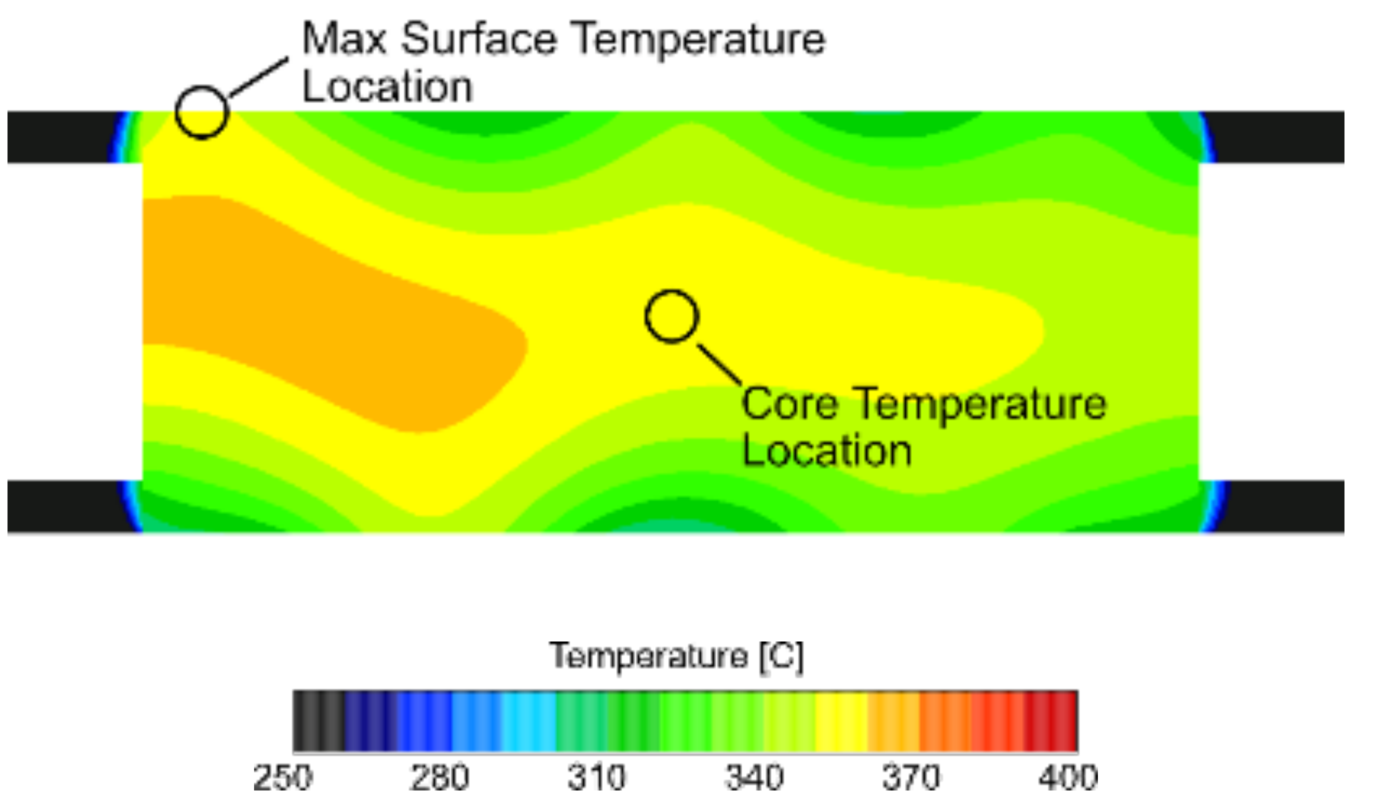


Sample Simulation Results – Existing Quench

- Significant temperature gradients exist, particularly near the start of quenching



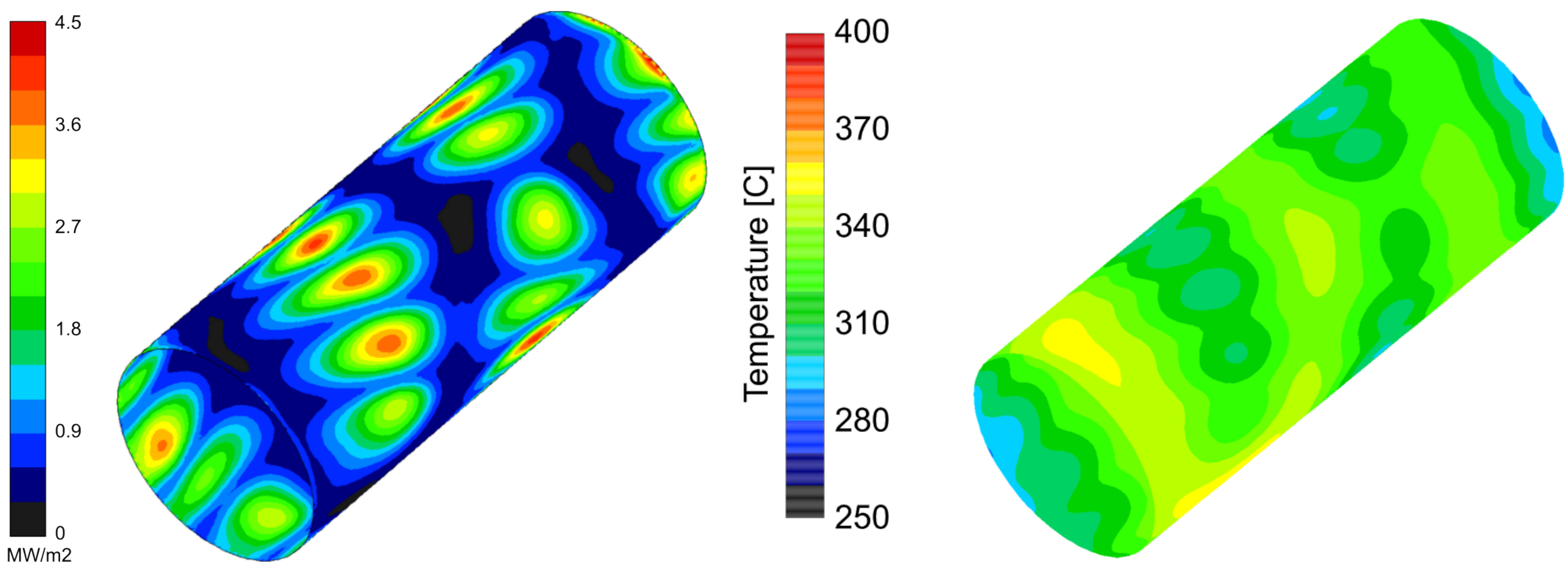
- Negative gradient around 2.5 s is artifact of comparison locations



Source of Non-Uniform Cooling

Heat flux distribution shows uneven pattern of cooling

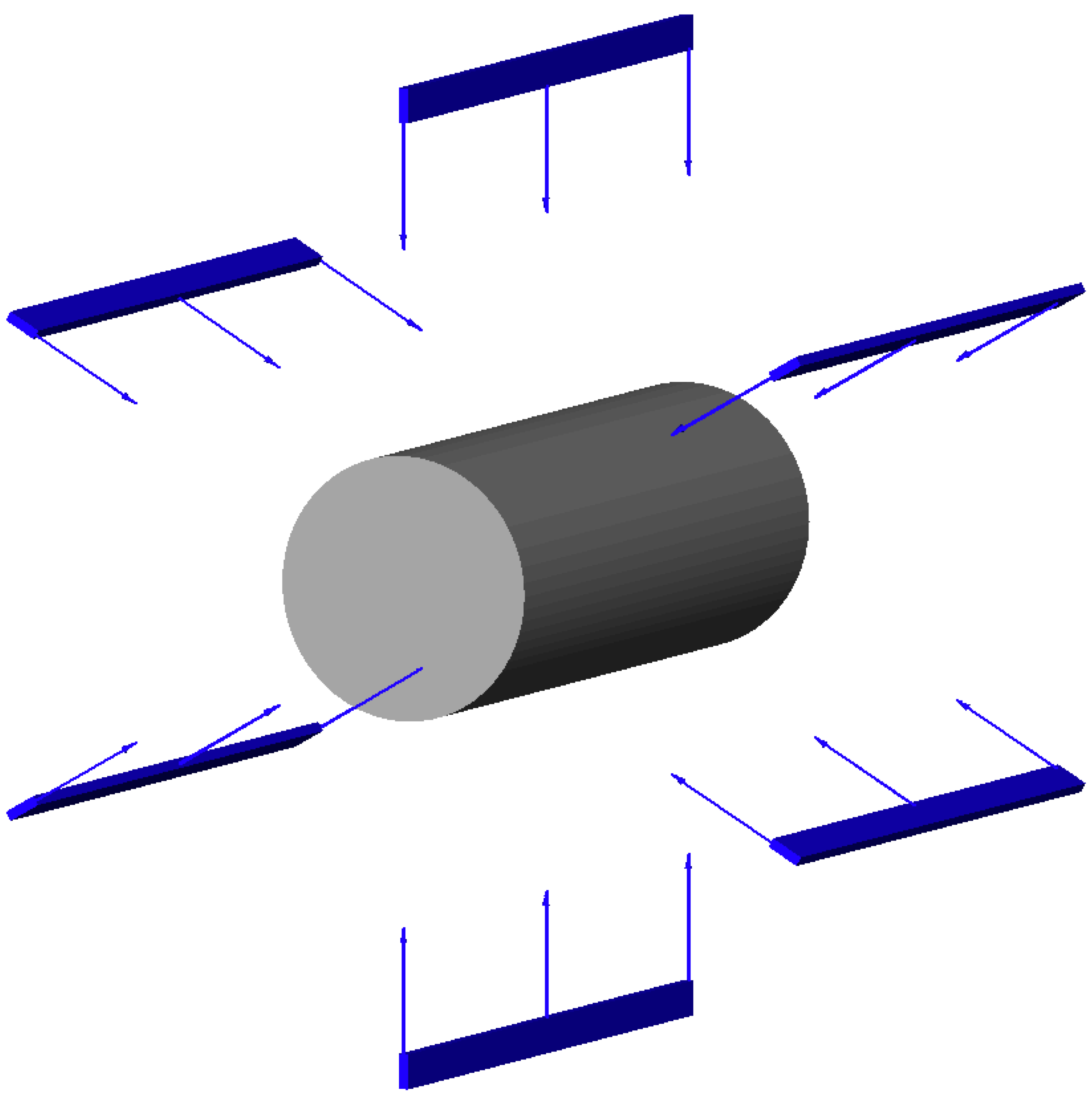
Resulting surface temperature distribution at 2.5 seconds into quench reflects uneven heat flux

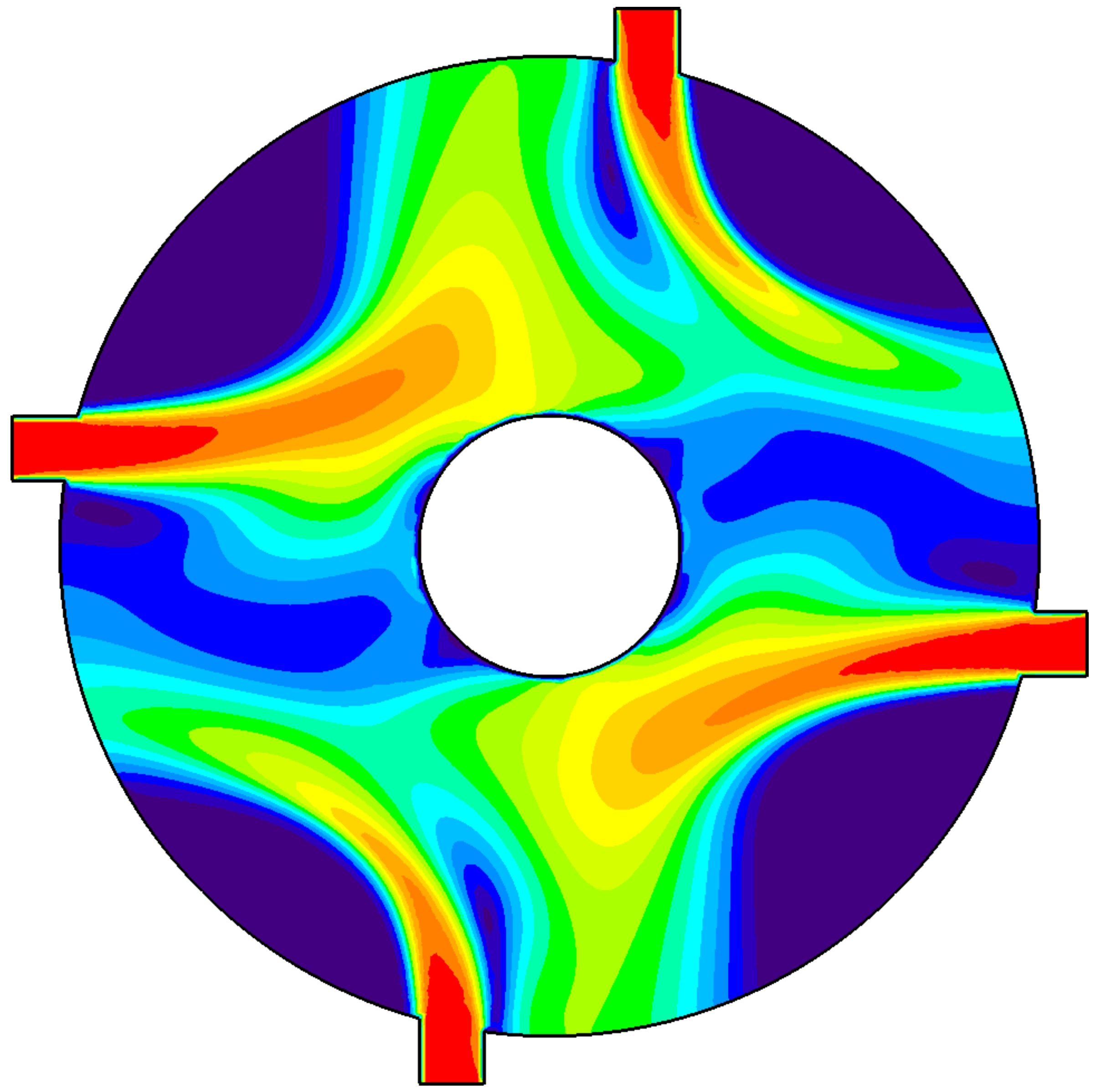


System Improvement Plan

- Develop quench system that provides better uniformity (and higher heat fluxes)
- Incorporate into mechanical design
- Assess impact on induction heating
- Determine cooling rate of complete system
- If successful, implement in dilatometer

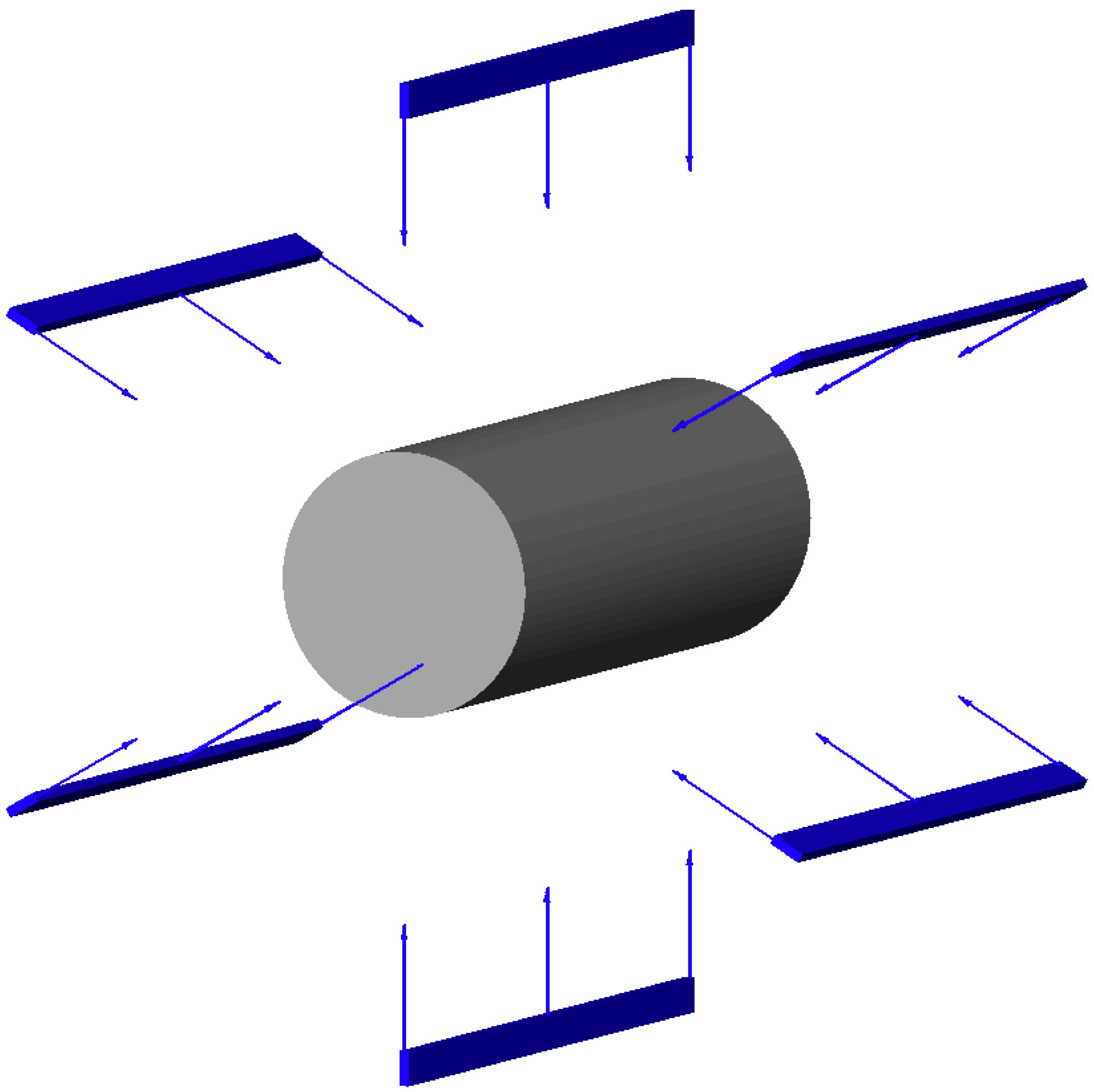
Initial Development Concepts – Axially Aligned Slots

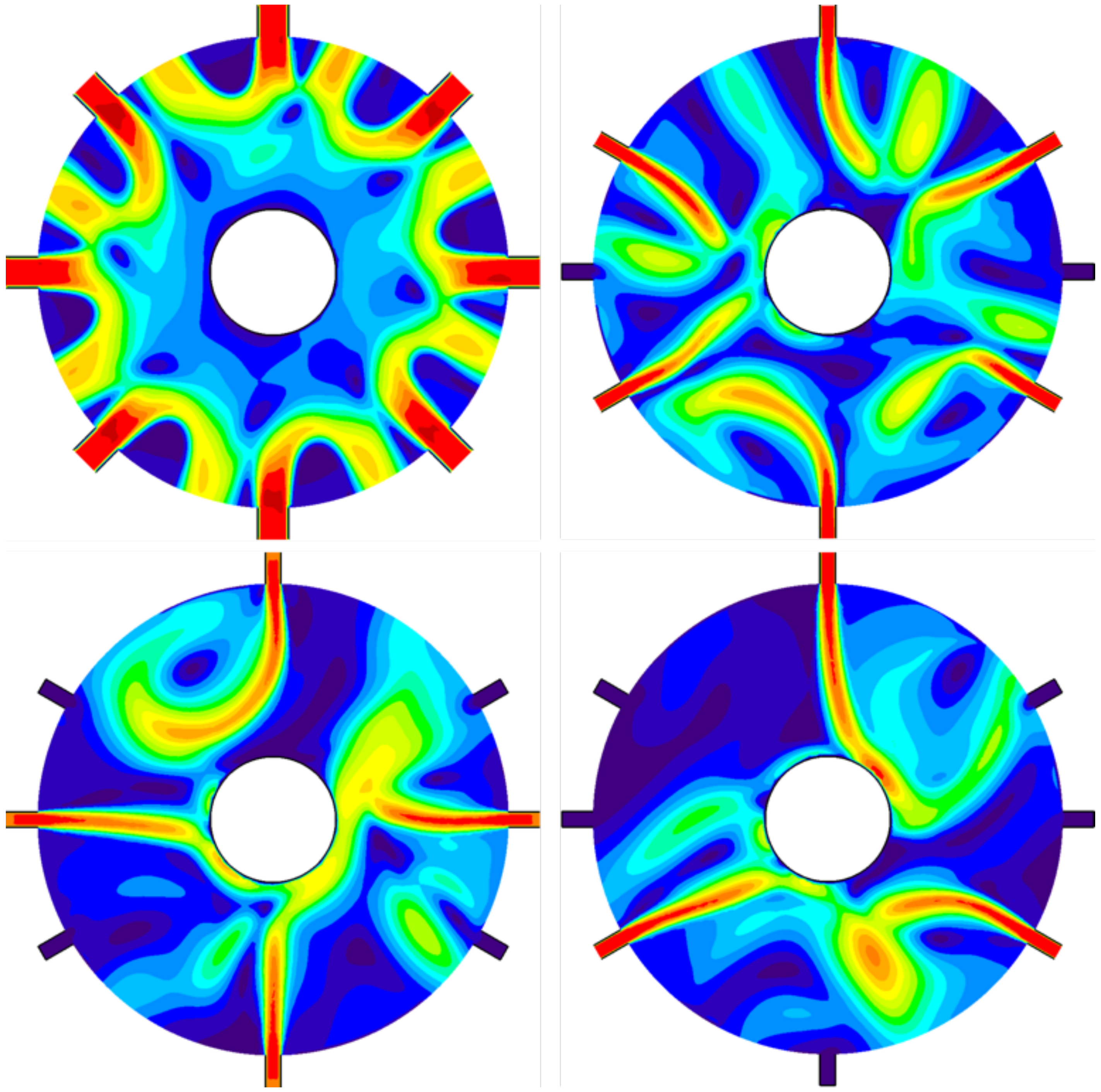




Swirl concept

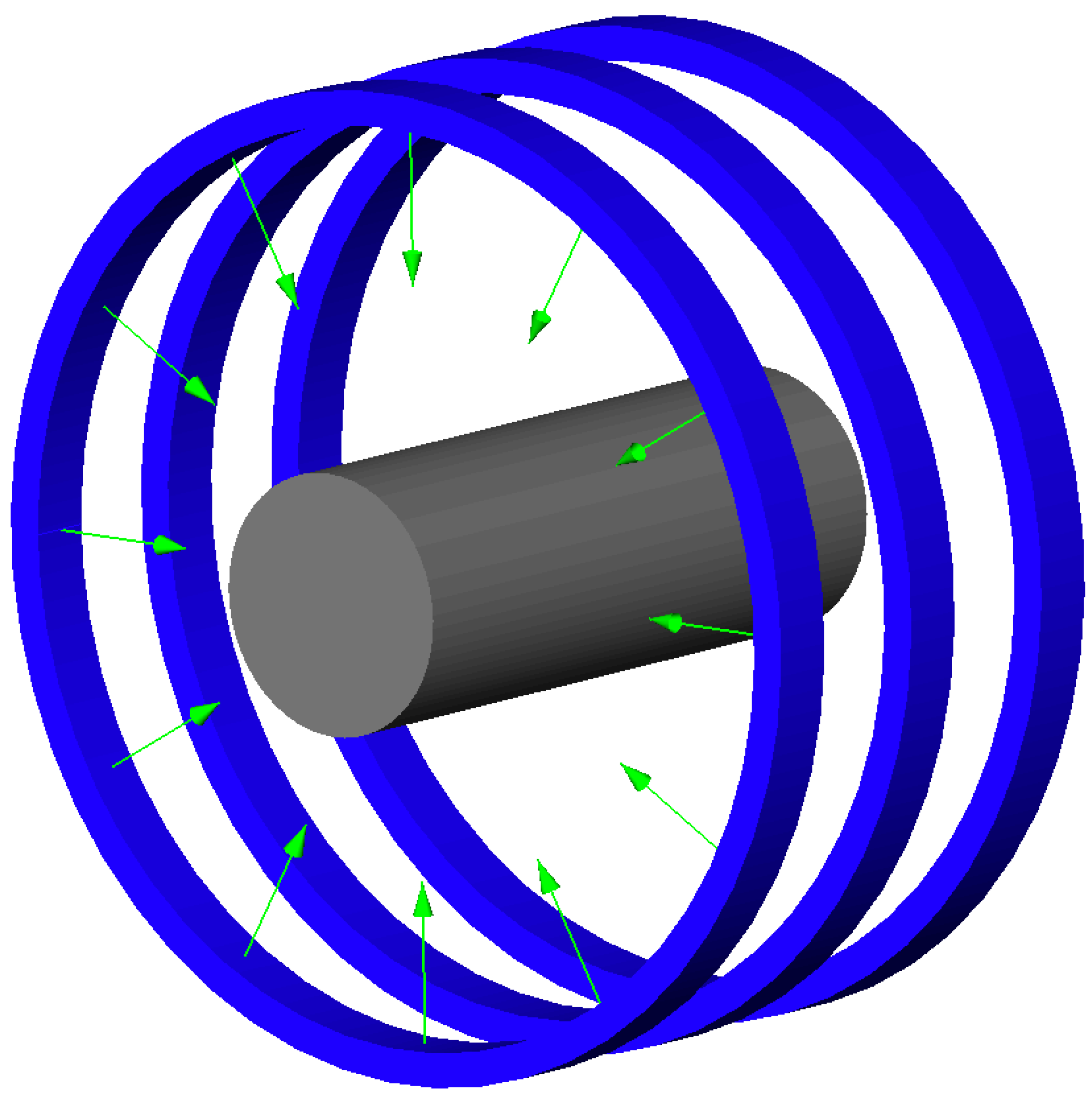
Initial Development Concepts – Axially Aligned Slots

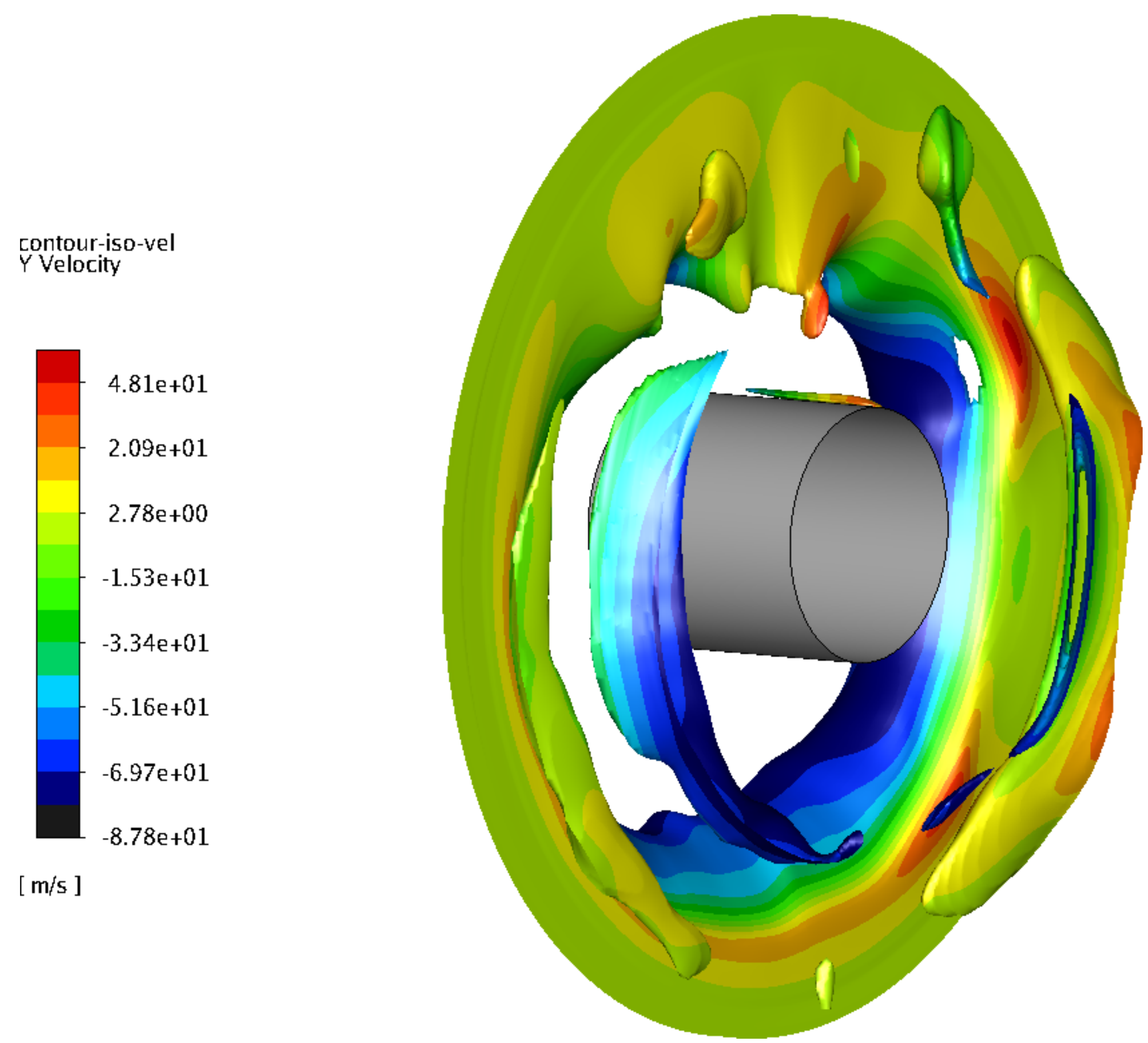




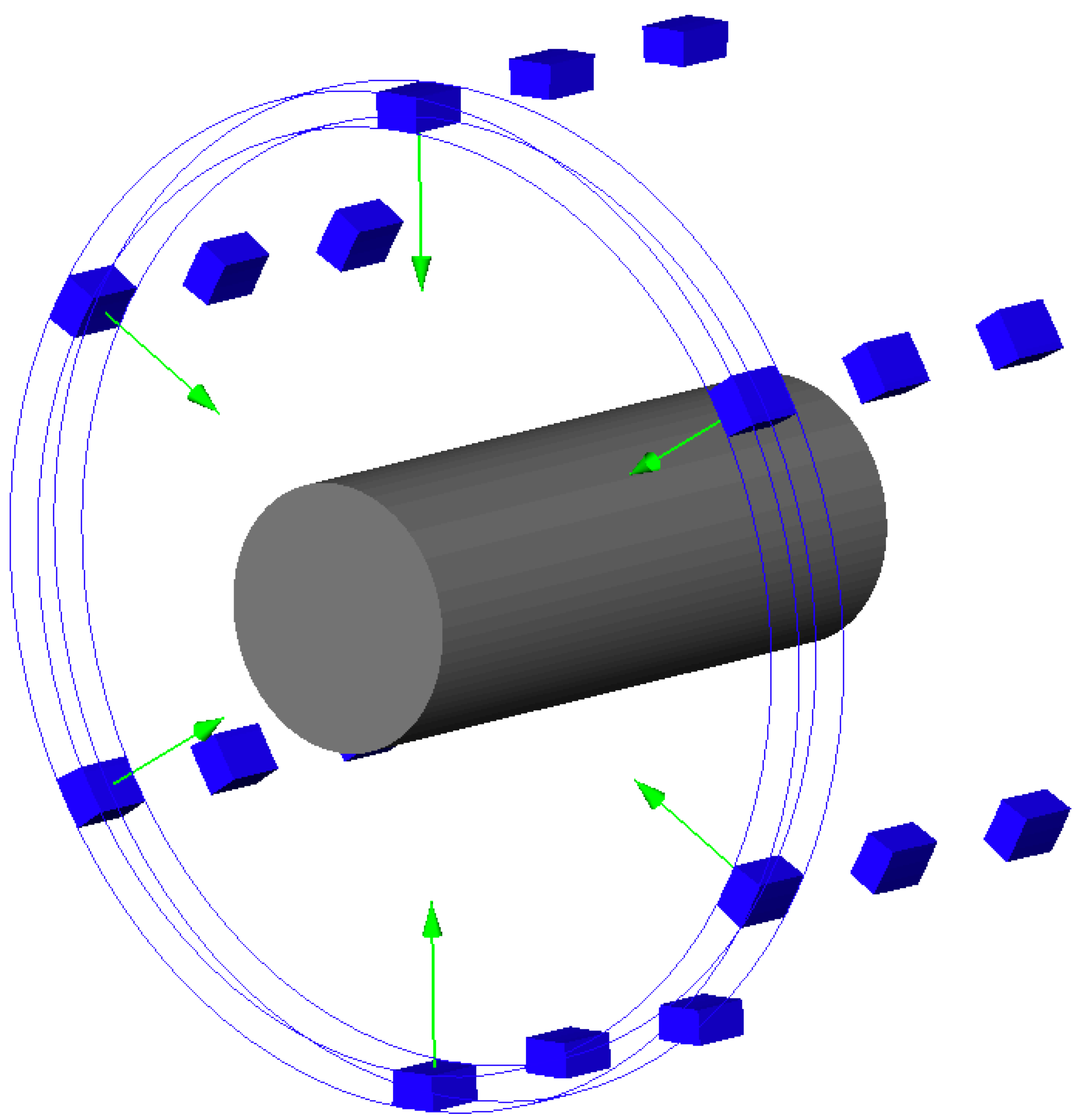
Different number of impinging slots

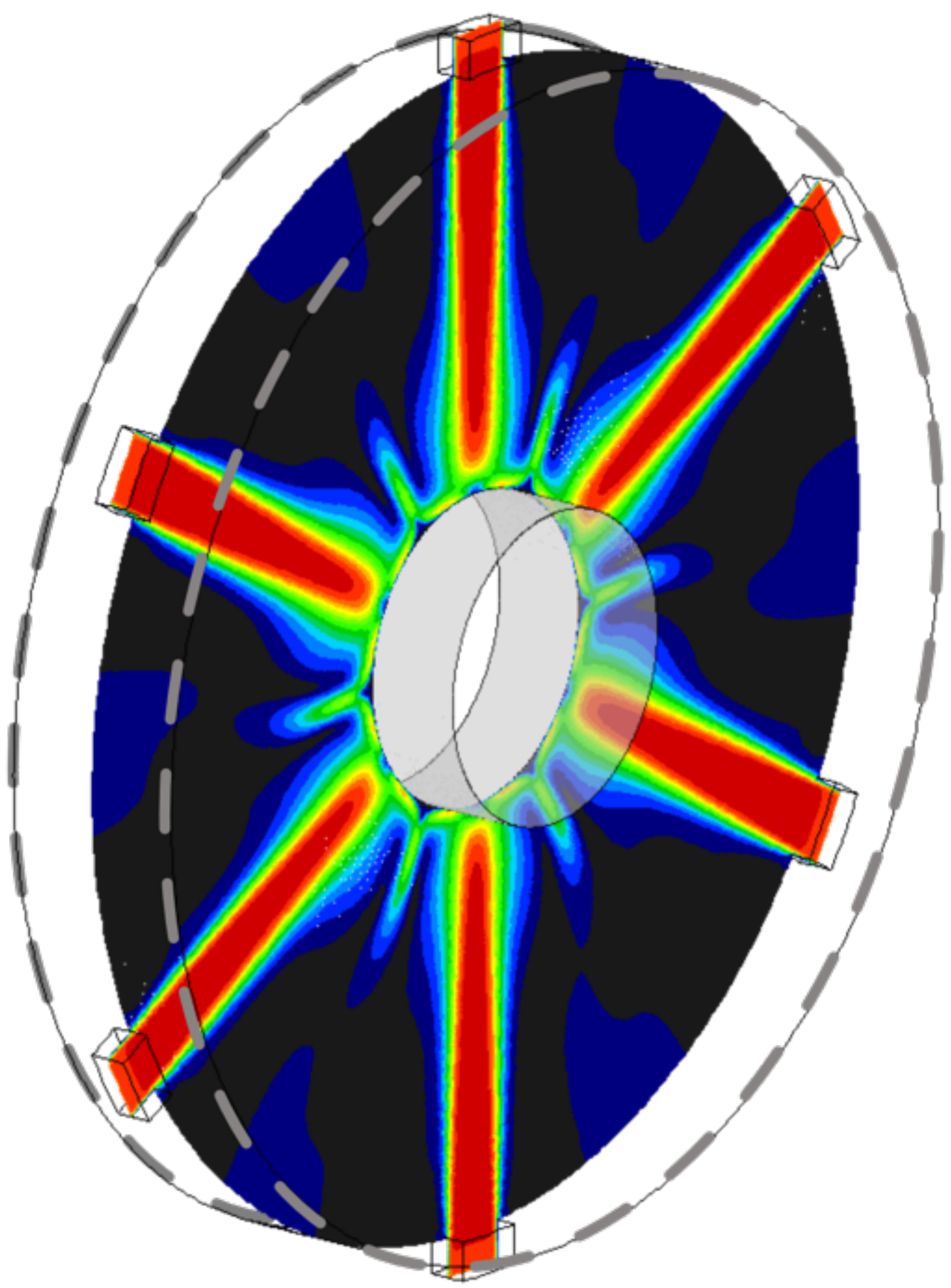
Initial Development Concepts – Ring Slots





Initial Development Concepts – Array of Slot Nozzles





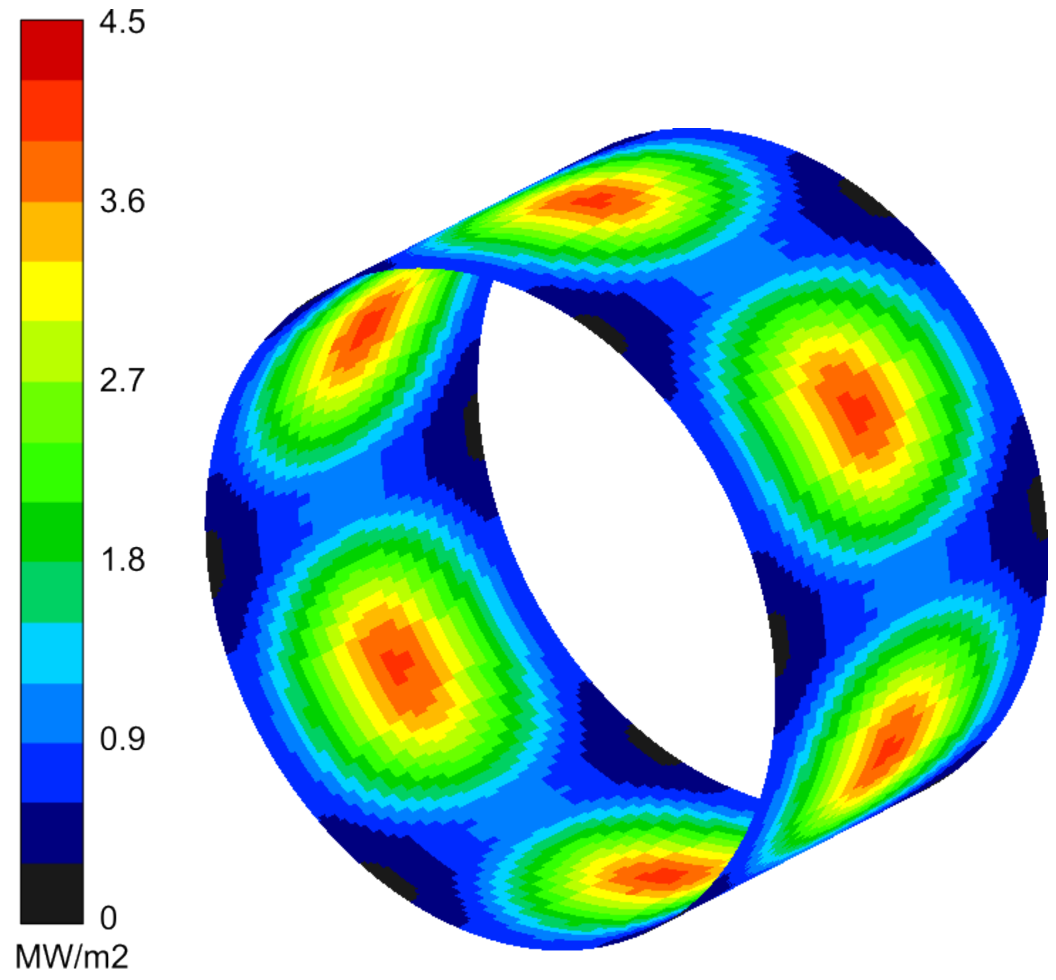
Optimization of Nozzle Parameters

Single row of nozzles simulated, with symmetry

Nozzle size kept constant

Spacing between nozzles varied

Designs assessed based on total heat flux and efficiency of cooling.



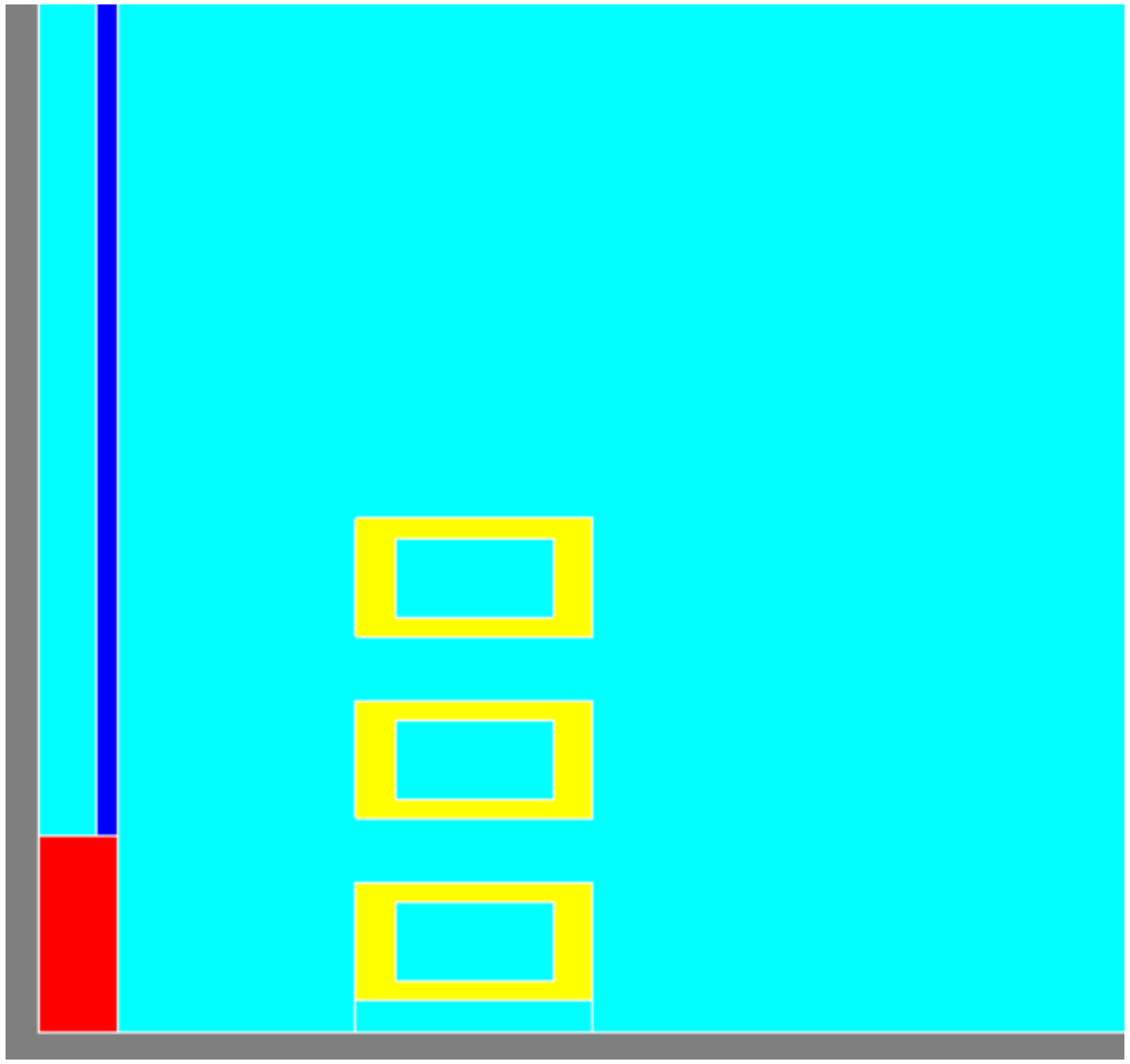
Row Spacing (mm)	Average Heat Flux (MW/m2)	RMS Deviation (%)	Efficiency (W/CFM)
2	1.51	56.1	73.0
2.25	1.61	55.4	77.7
2.5	1.60	56.5	85.8
3.4	1.36	63.7	99.0
4	1.22	66.3	104.5

Modeling of Dilatometer Tests

Heating and Cooling simulations separated due to differences in enthalpy of phase transformations

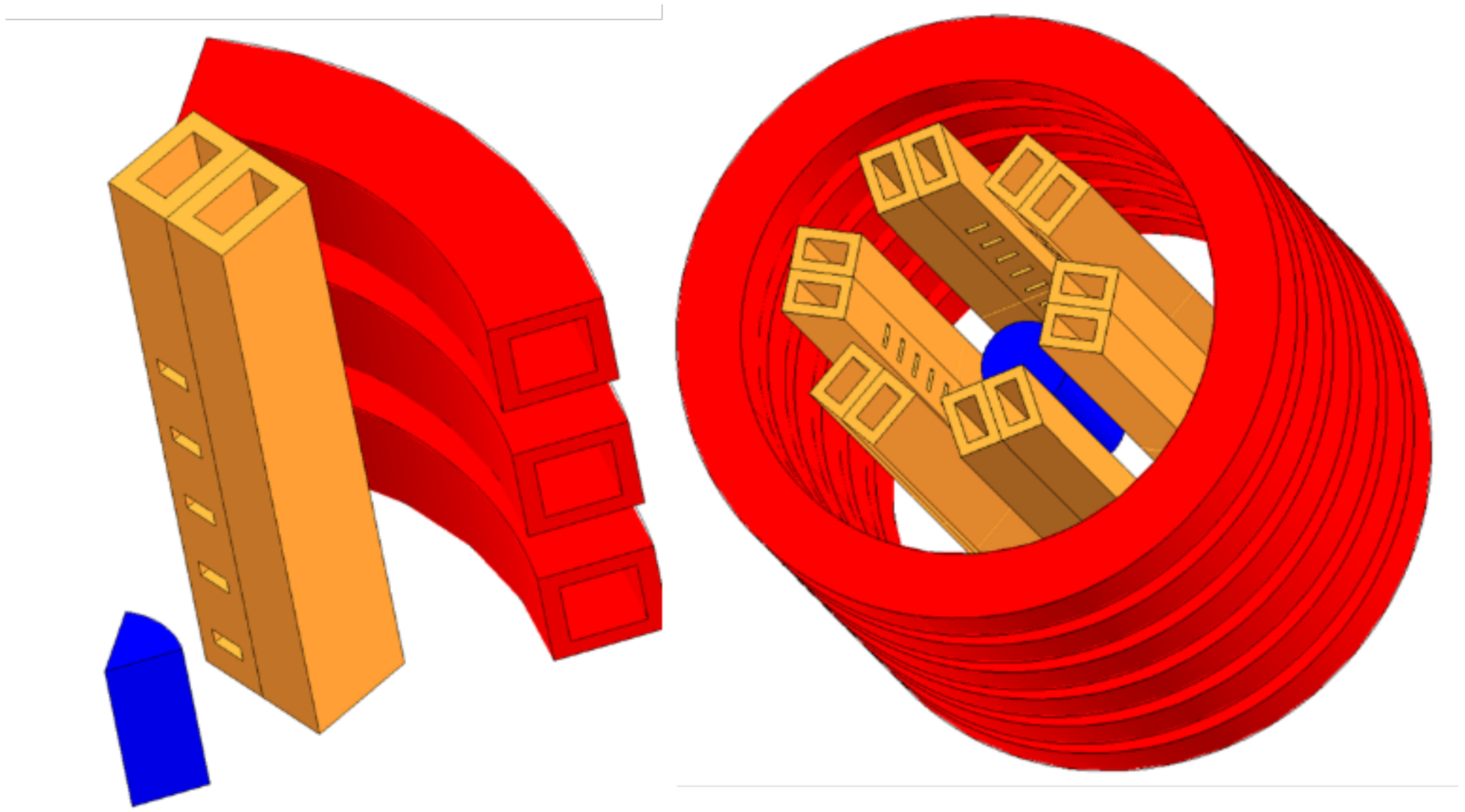
2D Program Flux Used for Determining Full Temperature Distributions

Cooling simulated through 3D CFD simulation



Induction Modeling

- Gas supply tubes placed inside induction coil
- Separate cooling needed for gas tubes
- 1/4 model used to take advantage of symmetry
- Models run with and without cooling tubes
- Models run at cold and hot steel properties



(A) (B)

Induction Results

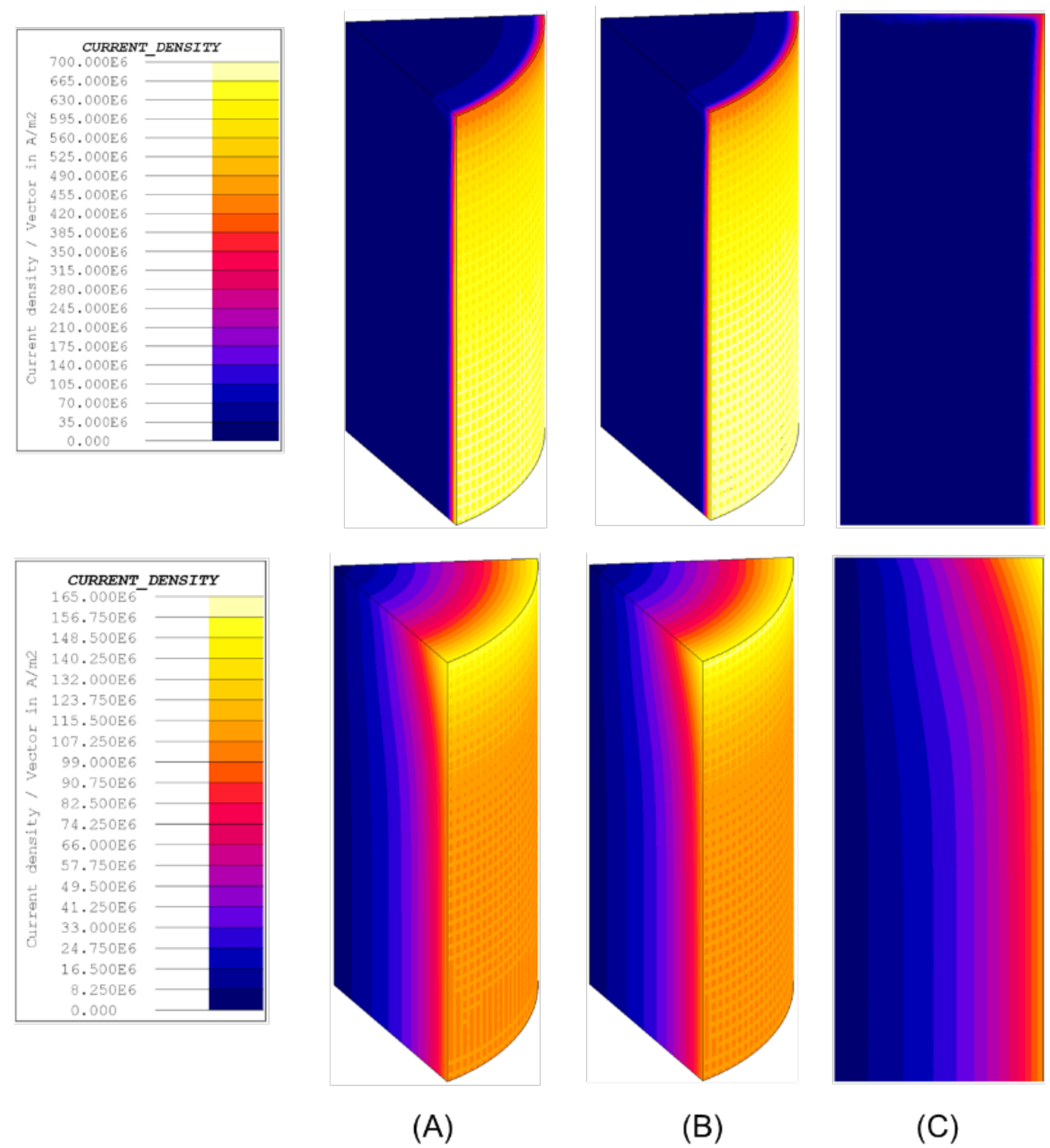
Results shown in top for cold steel properties and on bottom for hot steel properties.

A – With cooling fingers

B – Without cooling fingers

C – 2D results

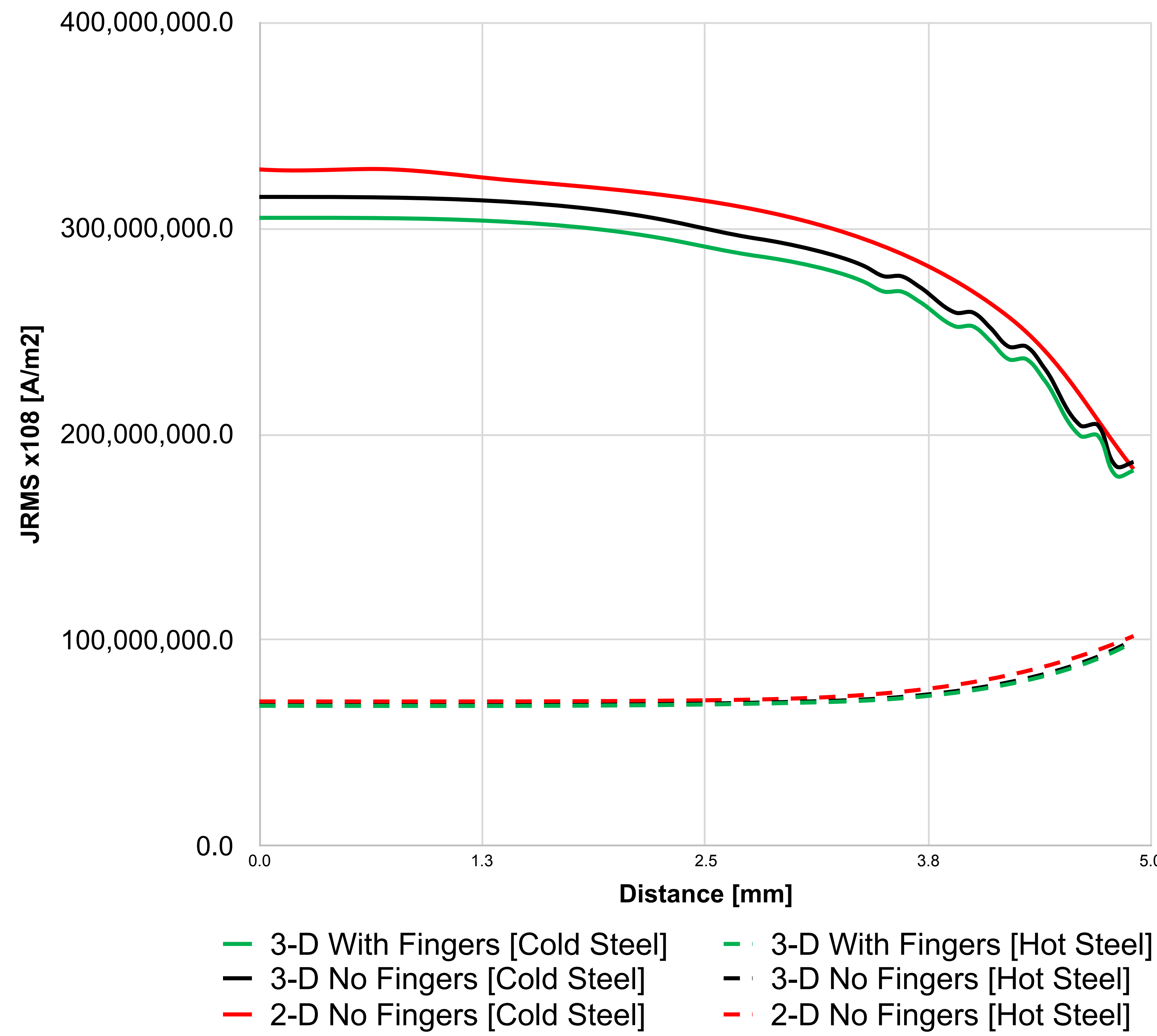
Presence of the fingers is shown to be minimal



Induction Results

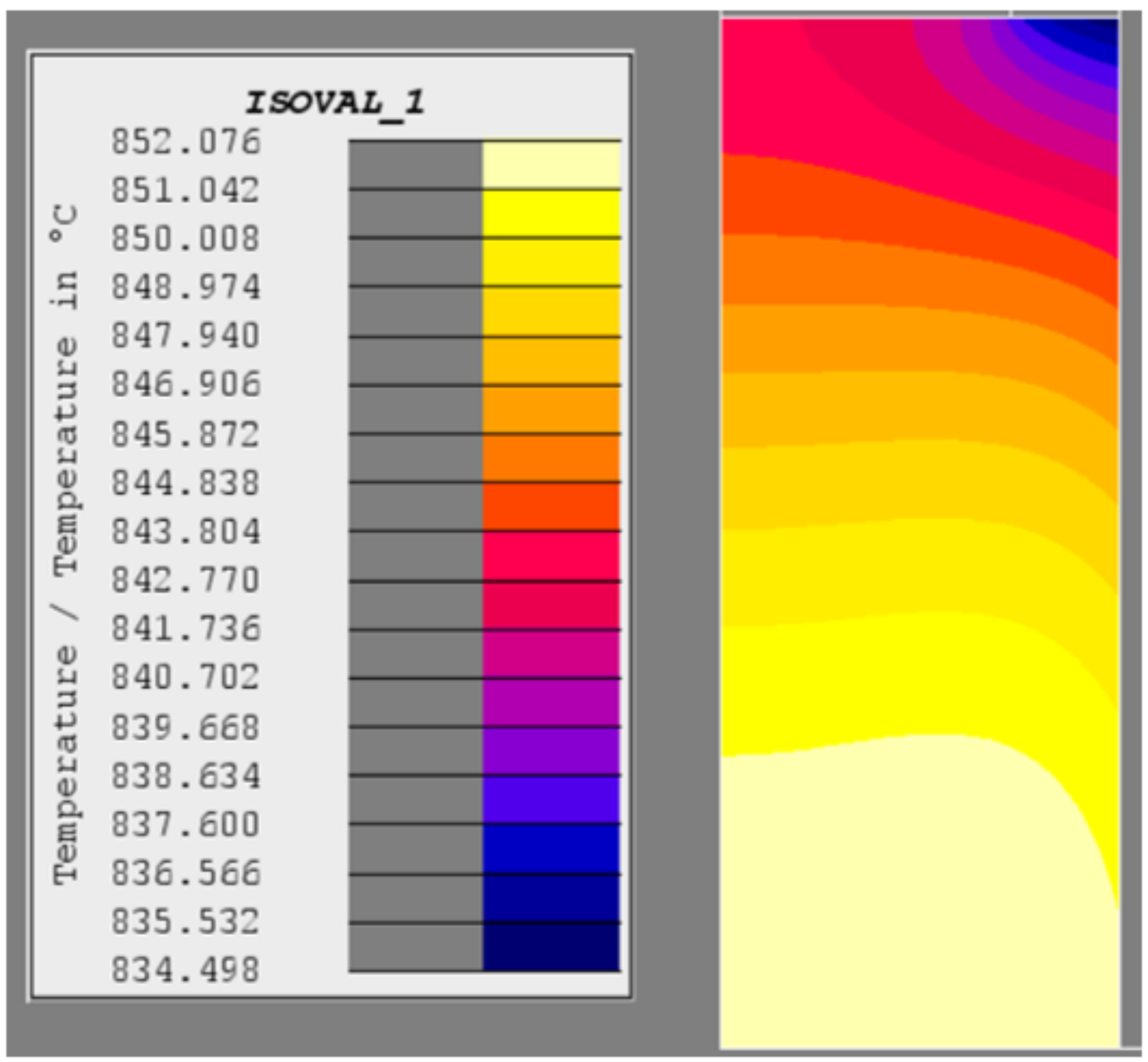
While there is a loss of efficiency due to the presence of the cooling fingers, the same current density can be achieved

Model	Case	P_{Part} [W]	P_{Coil} [W]	$P_{Fingers}$ [W]	P_{Total} [W]	Efficiency [N/A]
2-D No Fingers	Cold Steel	404	432	N/A	836	48%
3-D No Fingers		384	416	N/A	800	48%
3-D Fingers		362	413	508	1283	28%
2-D No Fingers	Hot Steel	79	430	N/A	509	15%
3-D No Fingers		75	414	N/A	489	15%
3-D With Fingers		74	412	510	996	7%



Initial Conditions for CFD Model

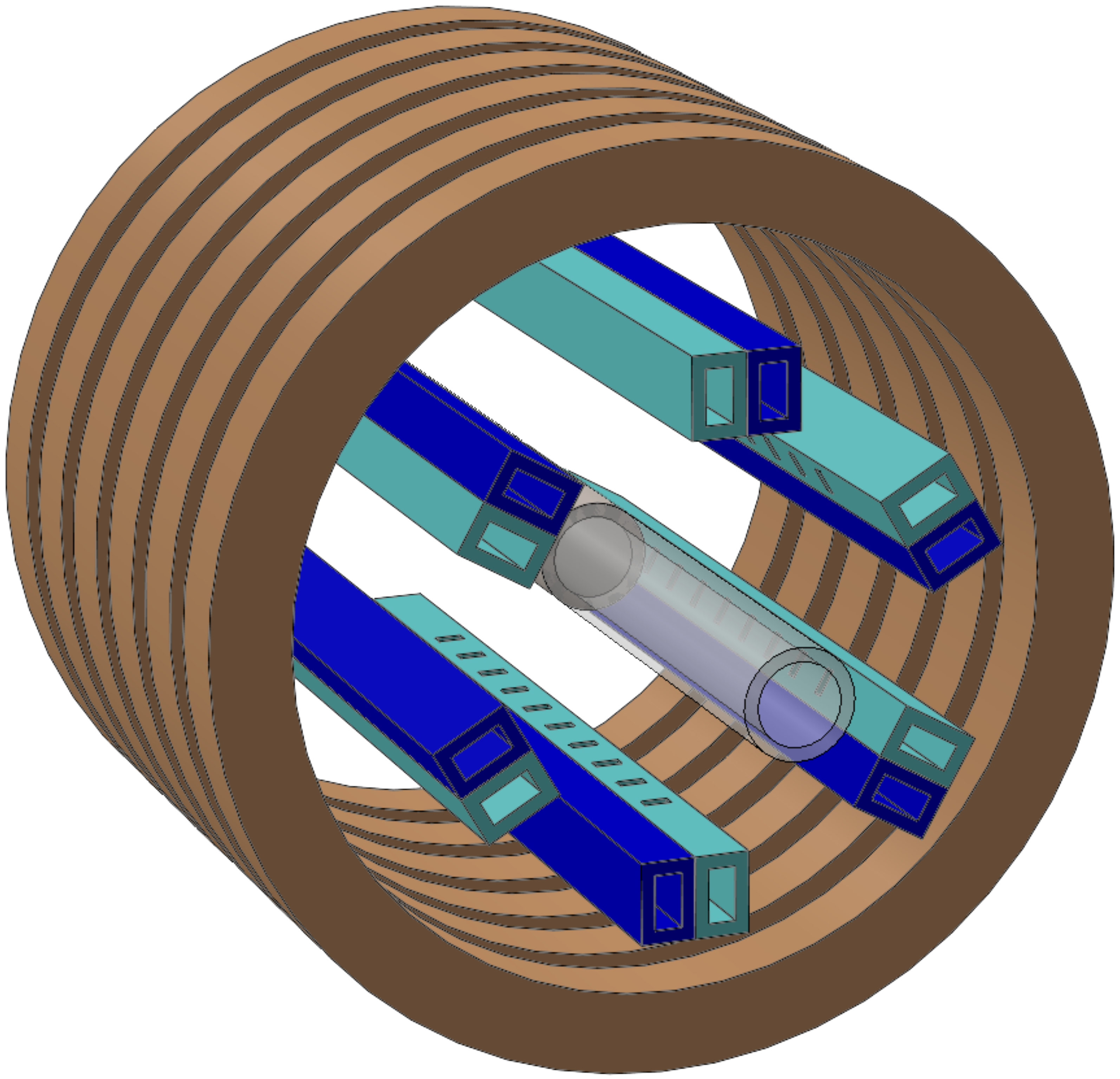
End of Holding



- From Flux model
- Effect of fused silica holding tube can be seen
- Minor radial gradients, except at end
- More significant axial gradient
- Same temperature distribution as previous study

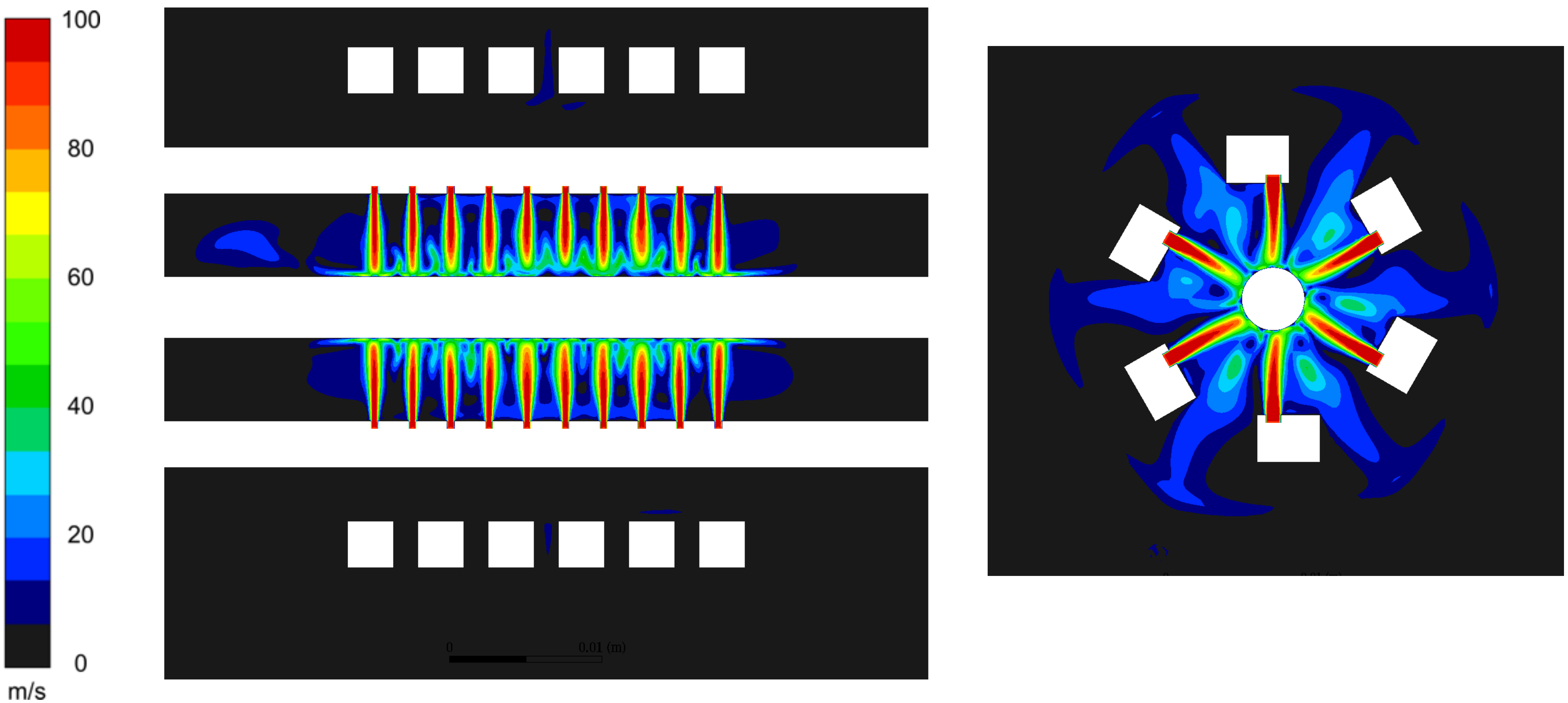
CFD Model Set-Up

- Helical coil approximated as a set of rings (same as induction model)
- Fully structured grid, 12.5 million cells
- Steady-state flow model
- ANSYS-Fluent using k-ω SST turbulence model
- 10 hour computational time on 3.0 GHz workstation with 32 cores



CFD Results

Flow is generally well-behaved, but some variations in the jets impinging the sample can be seen

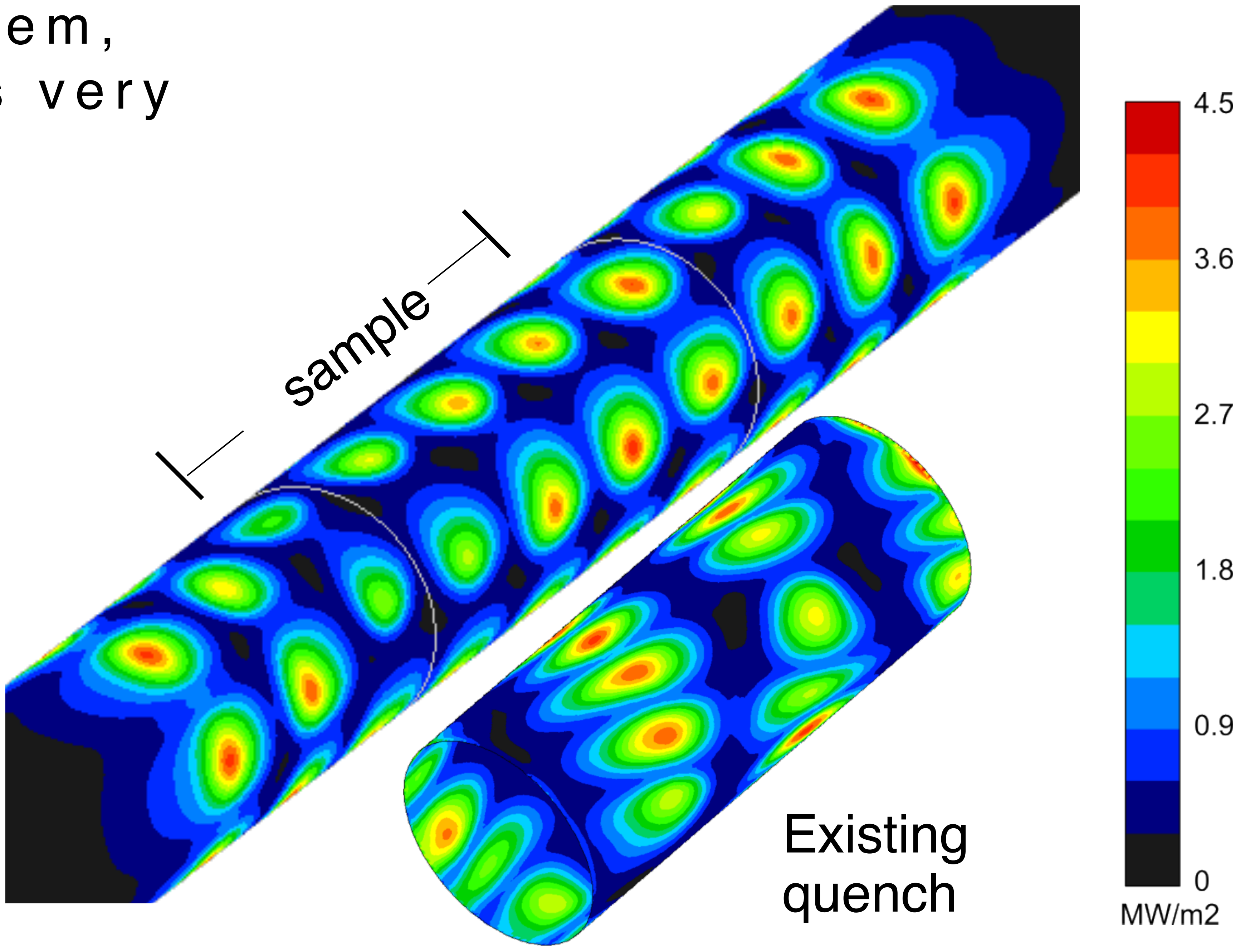


CFD Results

While pattern of heat flux is improved in proposed system, the range of heat fluxes is very similar to existing quench

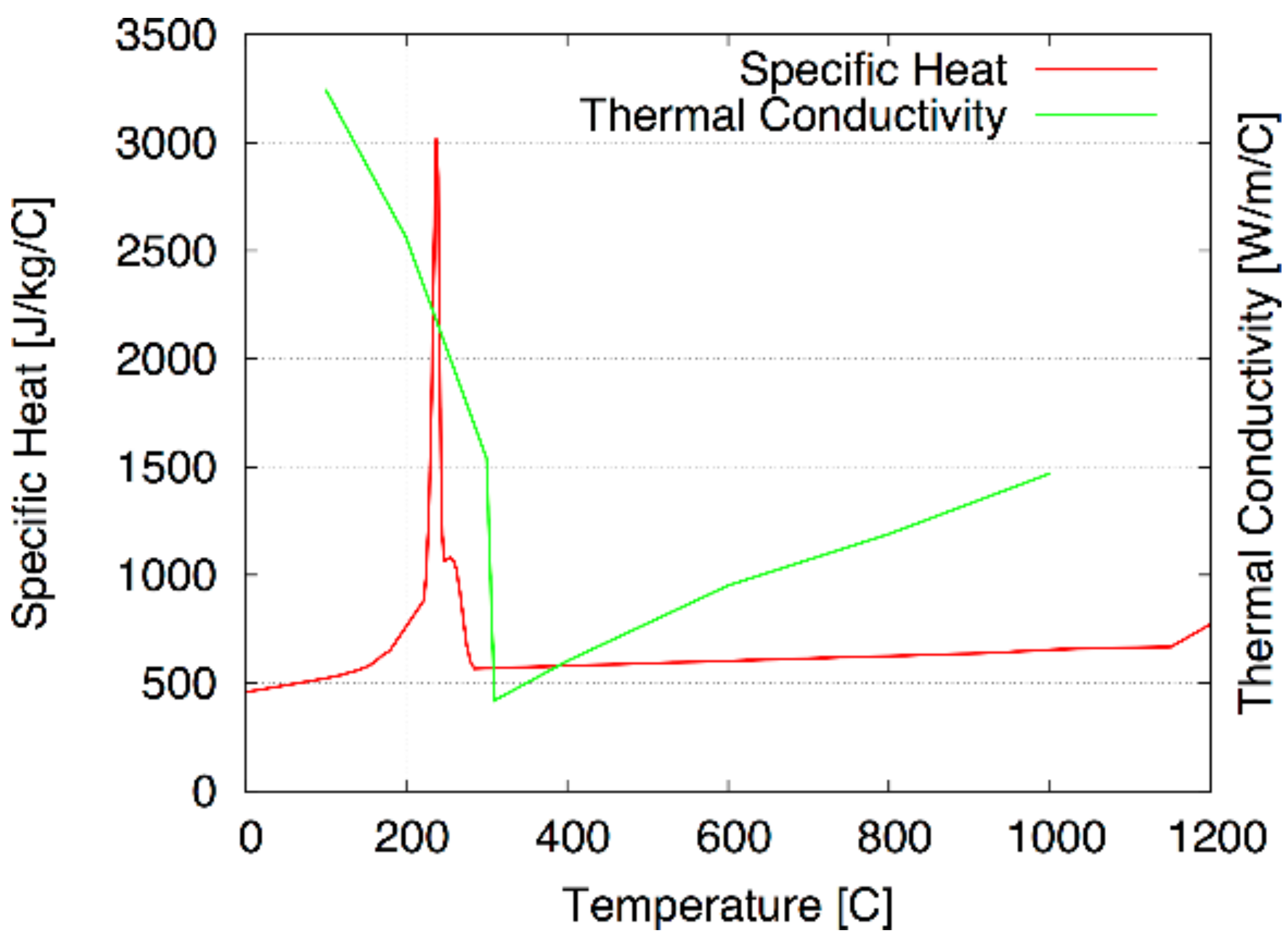
Pattern is somewhat more regular

Heat flux pattern then applied to transient model of sample (solids only)



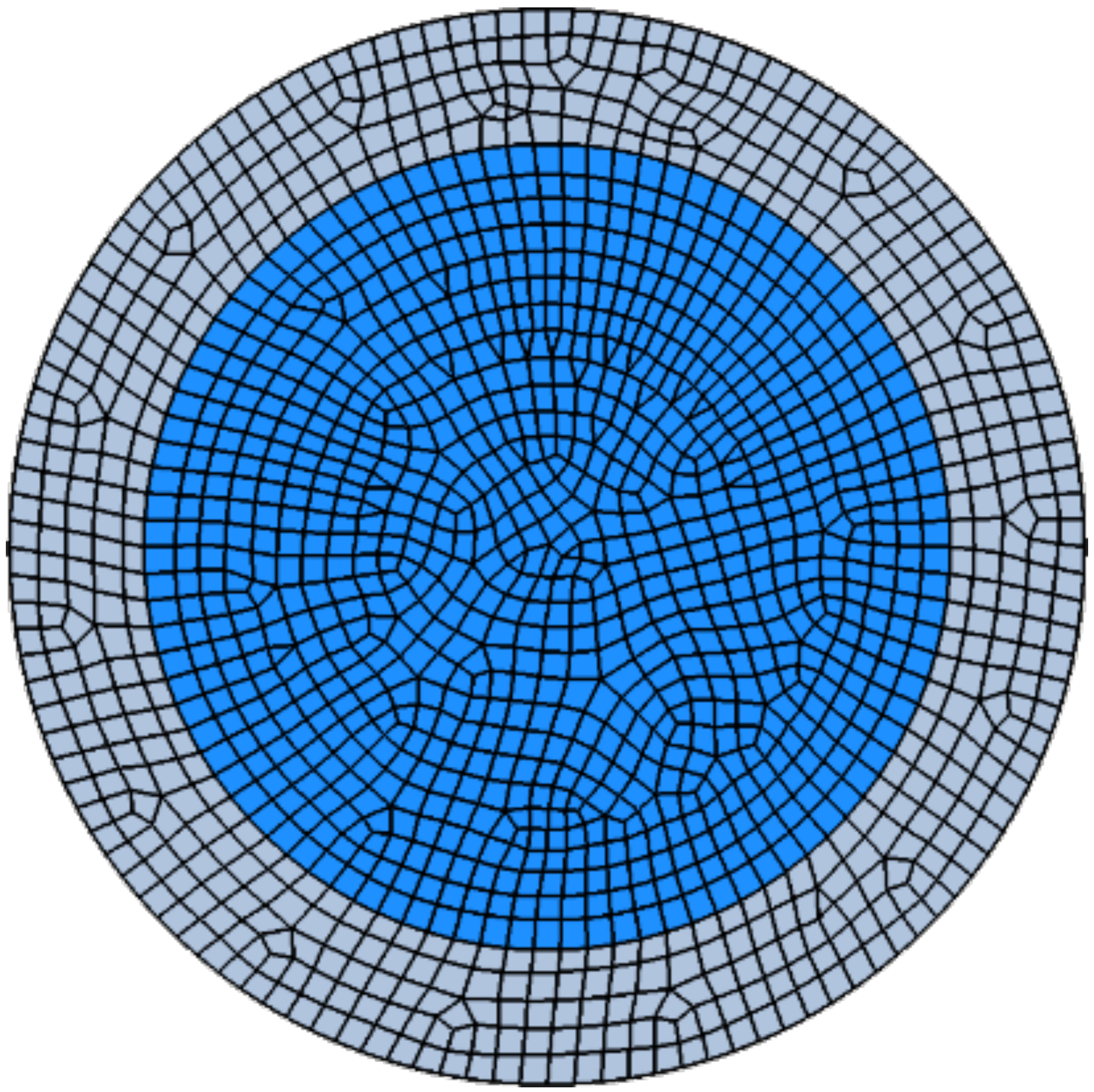
Material Thermal Properties

- Composite material properties constructed to account for phase change
- Transition point adjusted to match thermal data
- Latent heat based on DSC data for a different steel



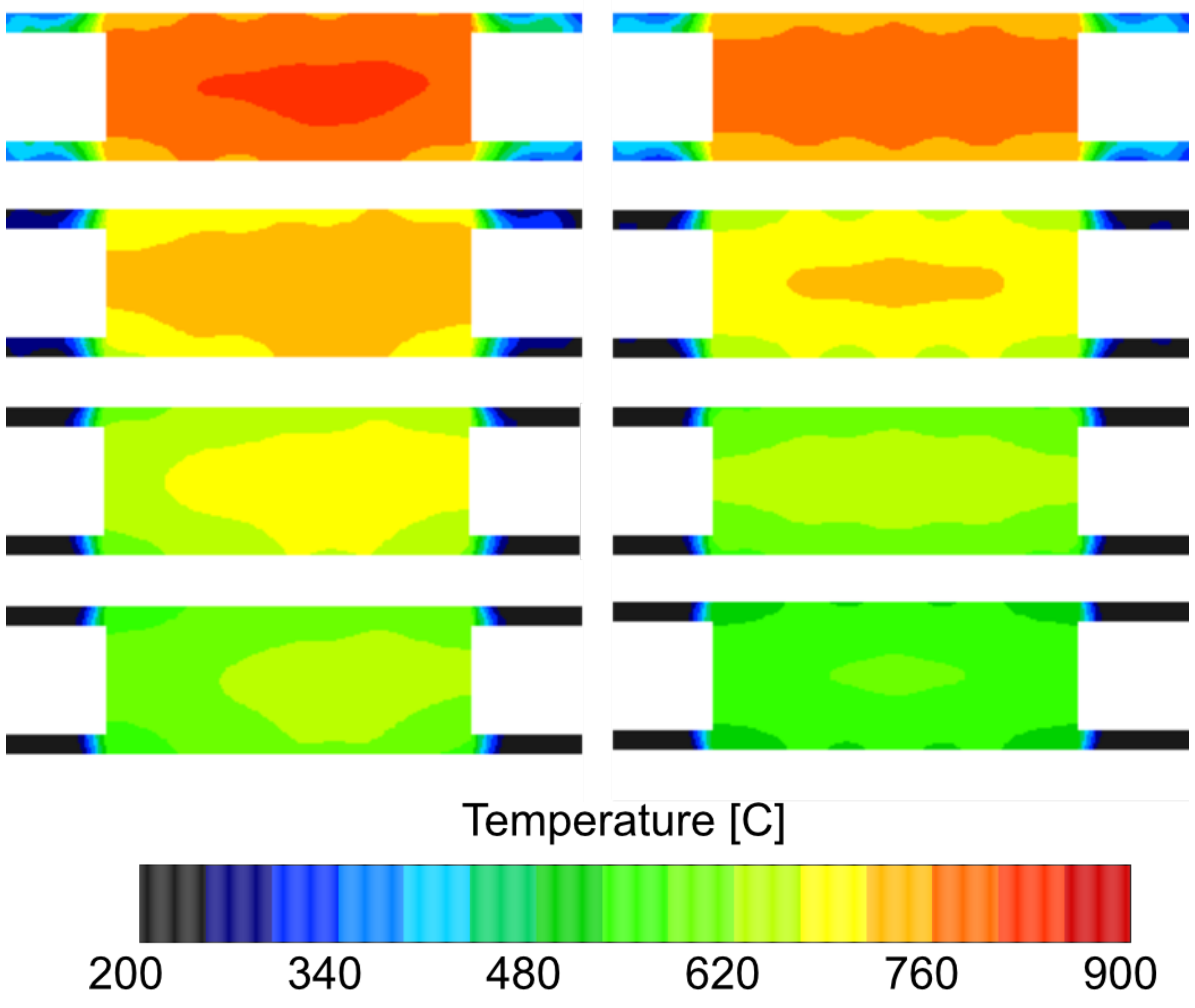
Sample Model

- No fluid domain
- Sample and fused quartz rods included in the simulation
- Convective heat transfer coefficient applied to sample and rod surfaces
- Radiation to surroundings included
- 320,000 computational cells
- 0.01 second time step



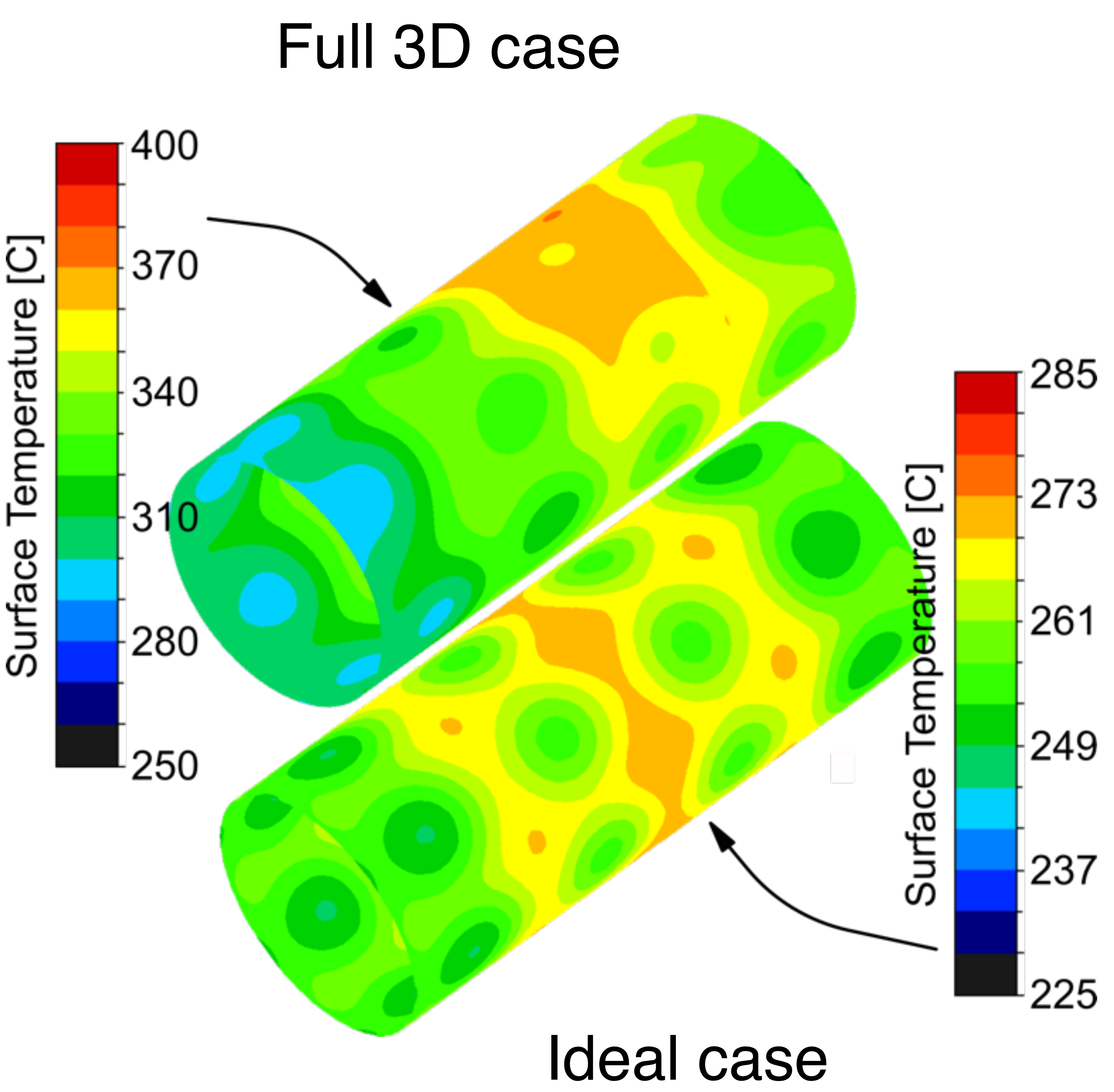
Transient Model Results

- Model was run for both the ideal case (right) represented by single row symmetry model and full 3D case (left)
- Variations in heat transfer seen in full 3D case cells
- 0.01 second time step



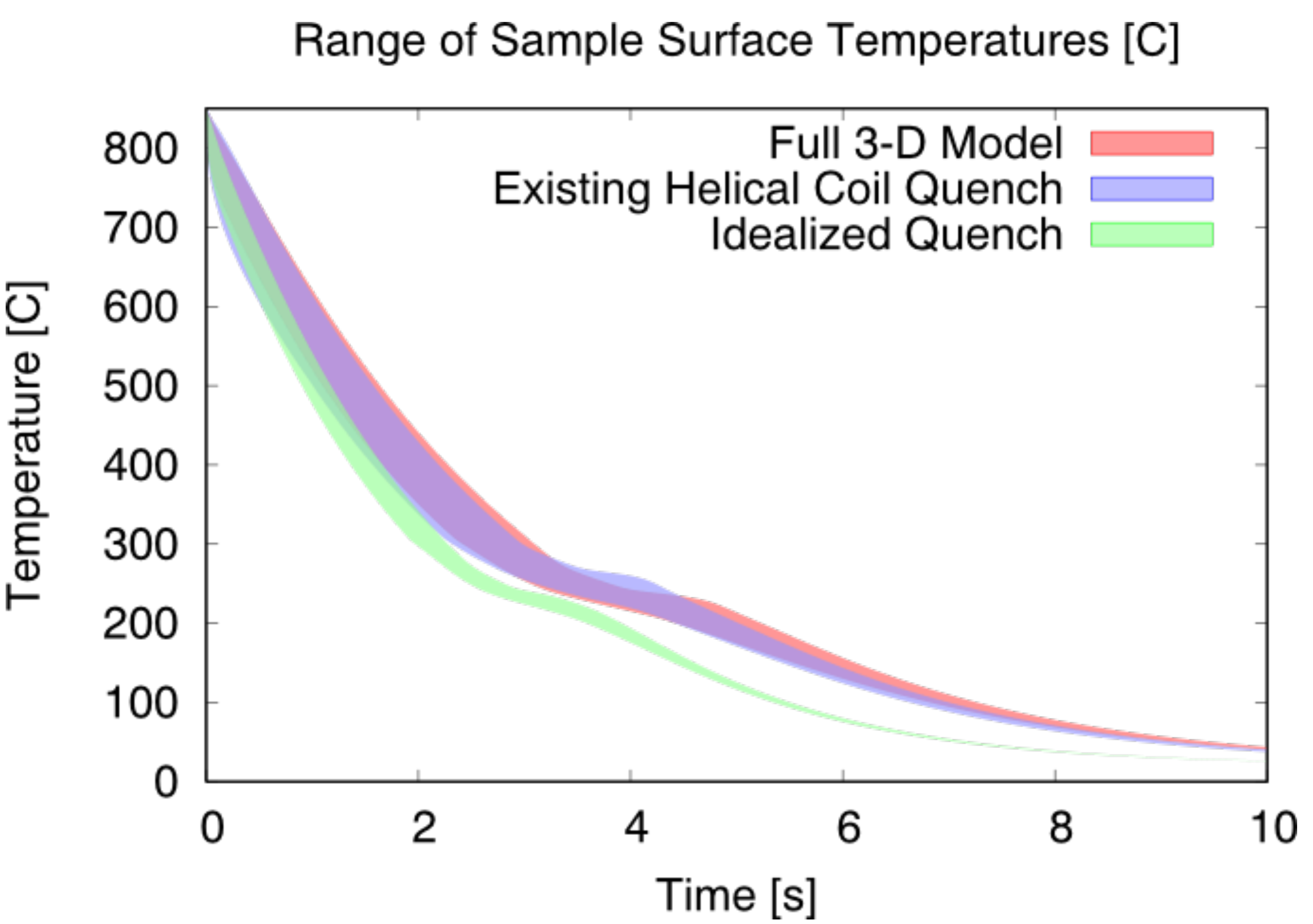
Transient Model Results

- Variations in heat transfer lead to reduced cooling and greater variability
- Results shown for 2.5 second into quench
- Note the different temperature scales



Transient Model Results

While the idealized model shows reduced variation in temperature and faster cooling, performance for the full 3D system is about the same as for the existing system.



Conclusions

- Previous studies of the TA instruments dilatometer have shown that there can be significant variations in sample temperature during cooling
- Cooling systems with improved cooling rate and uniformity can be shown for a reduced domain, ideal case
- Incorporation of the alternate cooling system into the dilatometer can be achieved without limiting heat-up rate
- Simulated cooling rates with full system showed no improvement, due to instability and interaction of the jets
- Improved cooling uniformity will require greater attention to the flow field stability within the system

FLUXTROL®