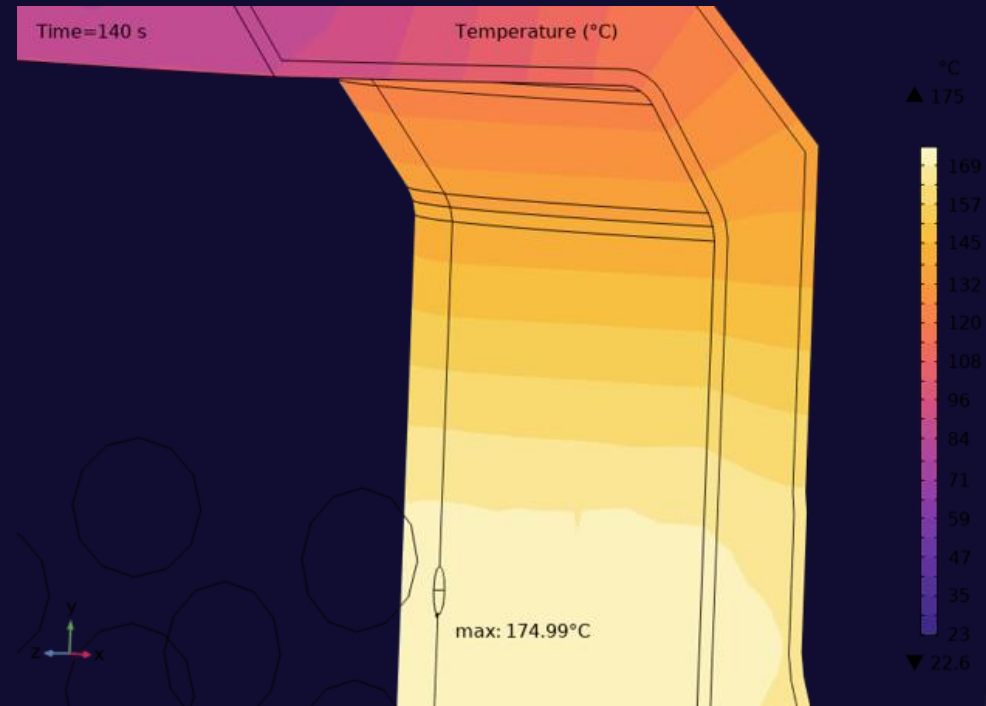


Multiphysics Modelling and Validation of an Induction Heating system for Precision Manufacturing

Heather Nute & Harvey Flanagan

The Manufacturing Technology Centre (MTC)



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The Manufacturing Technology Centre

Who we are

- Independent research and technology organisation based in the UK.
- Develop and deploy manufacturing technologies across industry.
- Bridge the gap between research and industrial implementation.
- Support sectors including aerospace, defence, energy, transport and emerging technologies

Modelling & Simulation Capability

- Electromagnetics
- Thermal analysis
- Structural mechanics
- Multiphysics simulation
- Process digitalisation and optimisation
- Digital engineering and virtual validation

Why induction heating?

The manufacturing challenge

Current Process

- Conventional oven-based heating
- Long heating cycles
- Limited localisation of heat input

Opportunity

- Rapid heating
- Contactless process
- Localised temperature control
- Increased manufacturing flexibility

Challenge

How do validate the process without excessive physical trials?



Industrial oven and indicative induction coil *ref: AI-generated illustration (OpenAI, 2026)*

Coupled Electromagnetic and Thermal Analysis

ELECTROMAGNETIC DOMAIN → THERMAL DOMAIN

1 COIL CURRENT $I(t)$, frequency f



2 MAGNETIC FIELD $\nabla \times E = -\partial B / \partial t$



3 EDDY CURRENTS $J = \sigma E$



4 JOULE HEATING $Q_{em} = J \cdot E$



TEMPERATURE $\rho C_p \partial T / \partial t = \nabla \cdot (k \nabla T) + Q_{em}$

↻ **FEEDBACK: T updates σ , μ , k and C_p**

Ferromagnetic alloys: add hysteresis losses below the Curie point.

Ref: COMSOL Induction Heating & Electromagnetic Heating; MIT OCW Heat Conduction.

Heat generation pathway

Physics Used

- AC/DC Module
- Heat Transfer Module

Model Features

- Temperature-dependent material properties
- Electromagnetic-to-thermal coupling
- Time-dependent thermal response
- Multiple induction heating system configurations

5 Workflow

Geometry → Electromagnetic Analysis → Heat Generation → Thermal Response → Validation

Efficient Resolution of the Skin effect

Computational efficiency strategy

Challenge

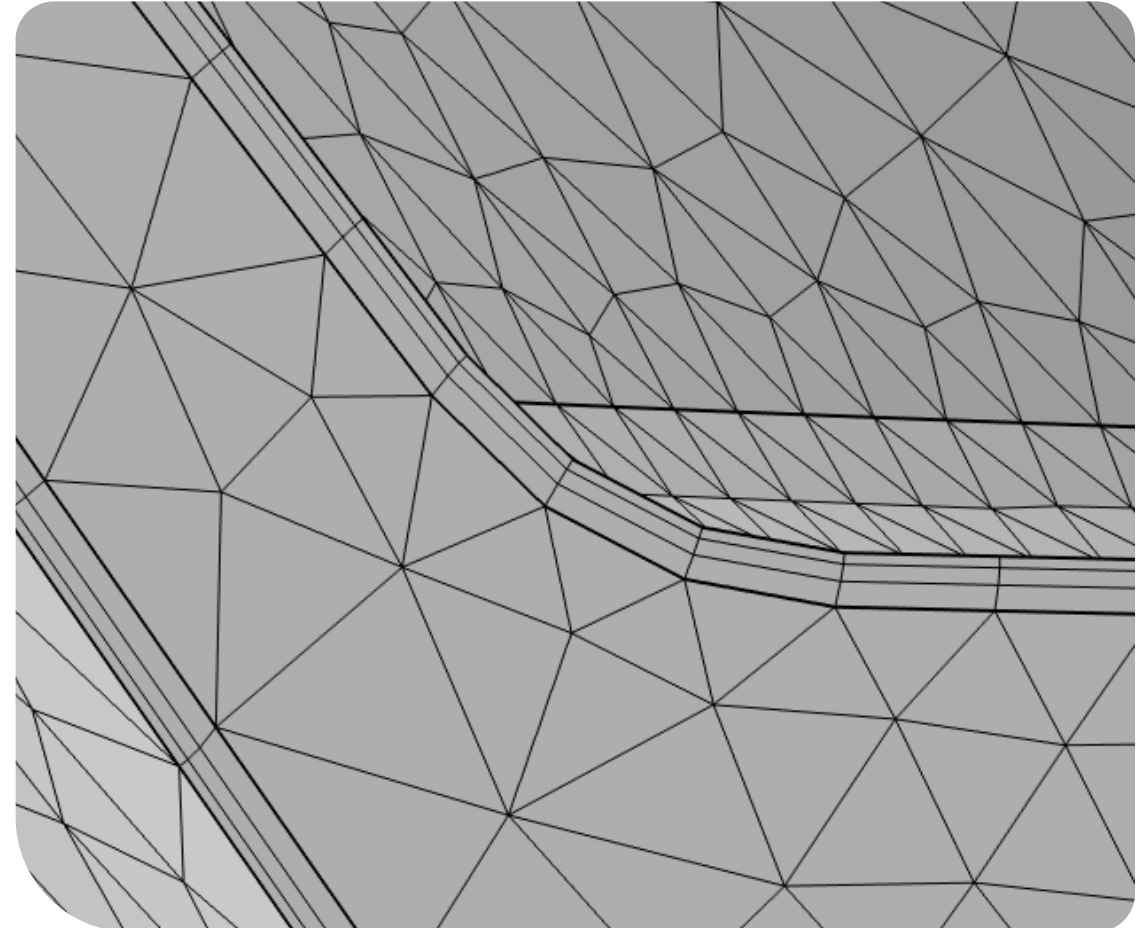
- Induction heating is dominated by skin-depth behaviour.

Approach

- Boundary-layer mesh at the surface
- Partitioned workpiece domains
- Electromagnetic solution restricted to relevant regions
- Full thermal solution retained

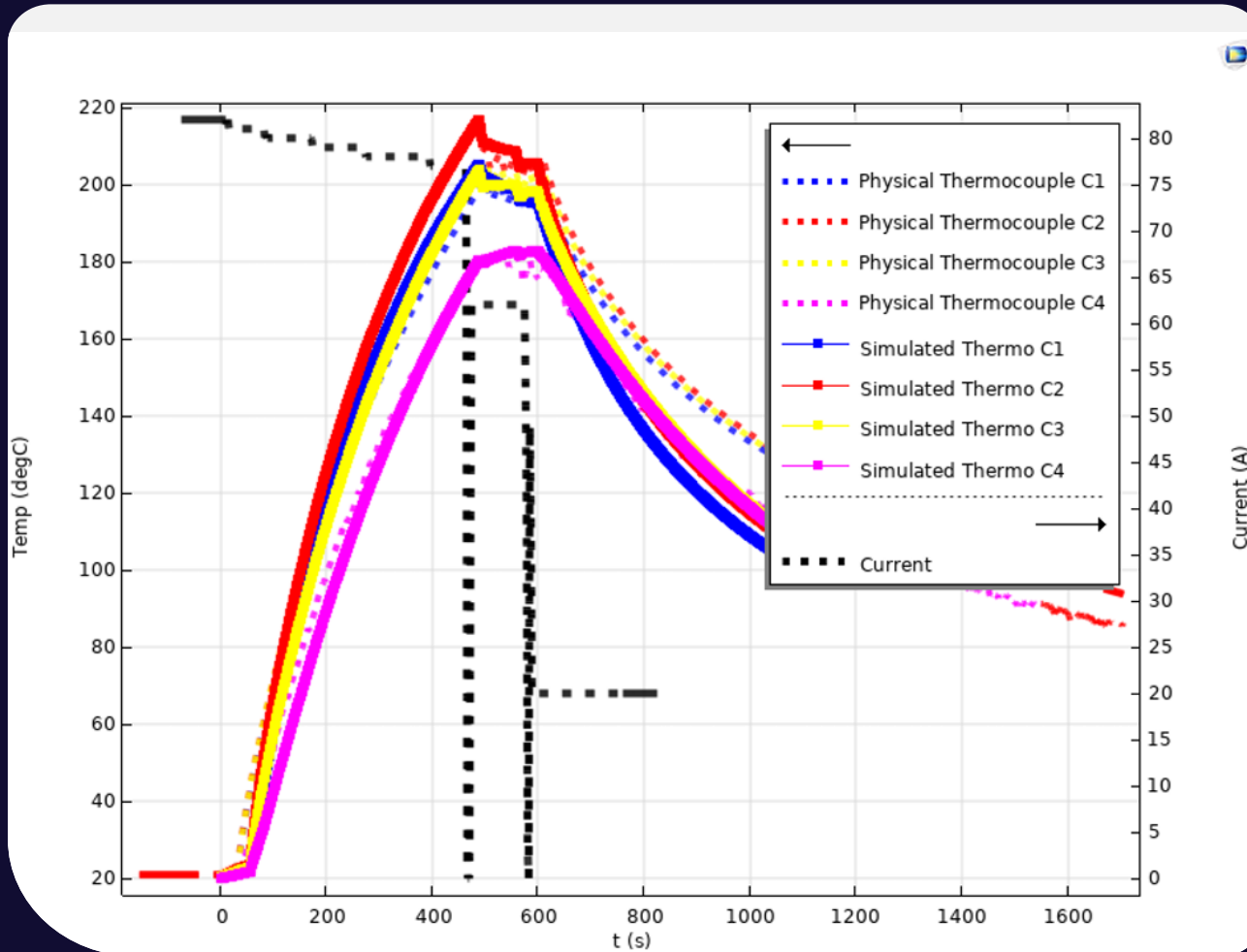
Benefits

- ✓ Reduced solution time
- ✓ Reduced model size
- ✓ Maintained thermal prediction accuracy
- ✓ Enables larger design studies



Split mesh strategy *ref: MTC MUSIC Phase 2 report*

Validation against physical trials



Building Confidence In The Digital Model

Validation Methods

- Thermocouple measurements
- Thermal imaging
- Physical induction heating trials

Comparison

- Temperature evolution
- Peak temperatures
- Heating response

Key Result

Strong agreement between simulation and experiment enabled confident application of the model for subsequent design investigations.

Investigation of Process Parameters

Using the model as an engineering tool

Parameters Investigated

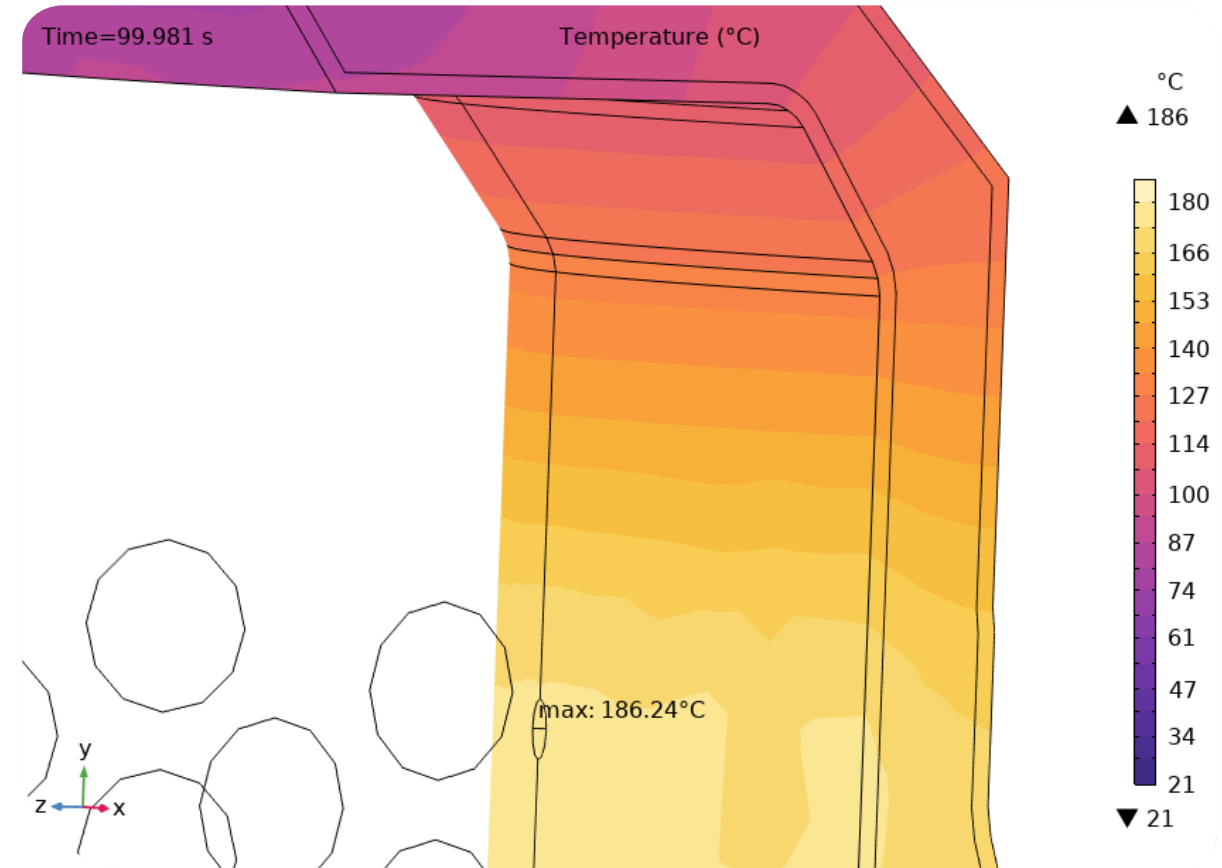
- Coil geometry
- Coil spacing
- Frequency
- Current
- Component geometry

Outputs

- Temperature distribution
- Heating rate
- Peak temperature
- Temperature uniformity

Purpose

- Assess the influence of key process variables
- Compare alternative induction heating configurations
- Support understanding of heating behaviour
- Inform future process development



Temperature Distribution on areas of interest, *ref: MTC MUSIC Phase 2 report*

Conclusions and Industrial impact

Key outcomes

Technical

- ✓ Validated electromagnetic-thermal simulation framework
- ✓ Efficient skin-depth modelling approach
- ✓ Applied across multiple geometries and heating configurations

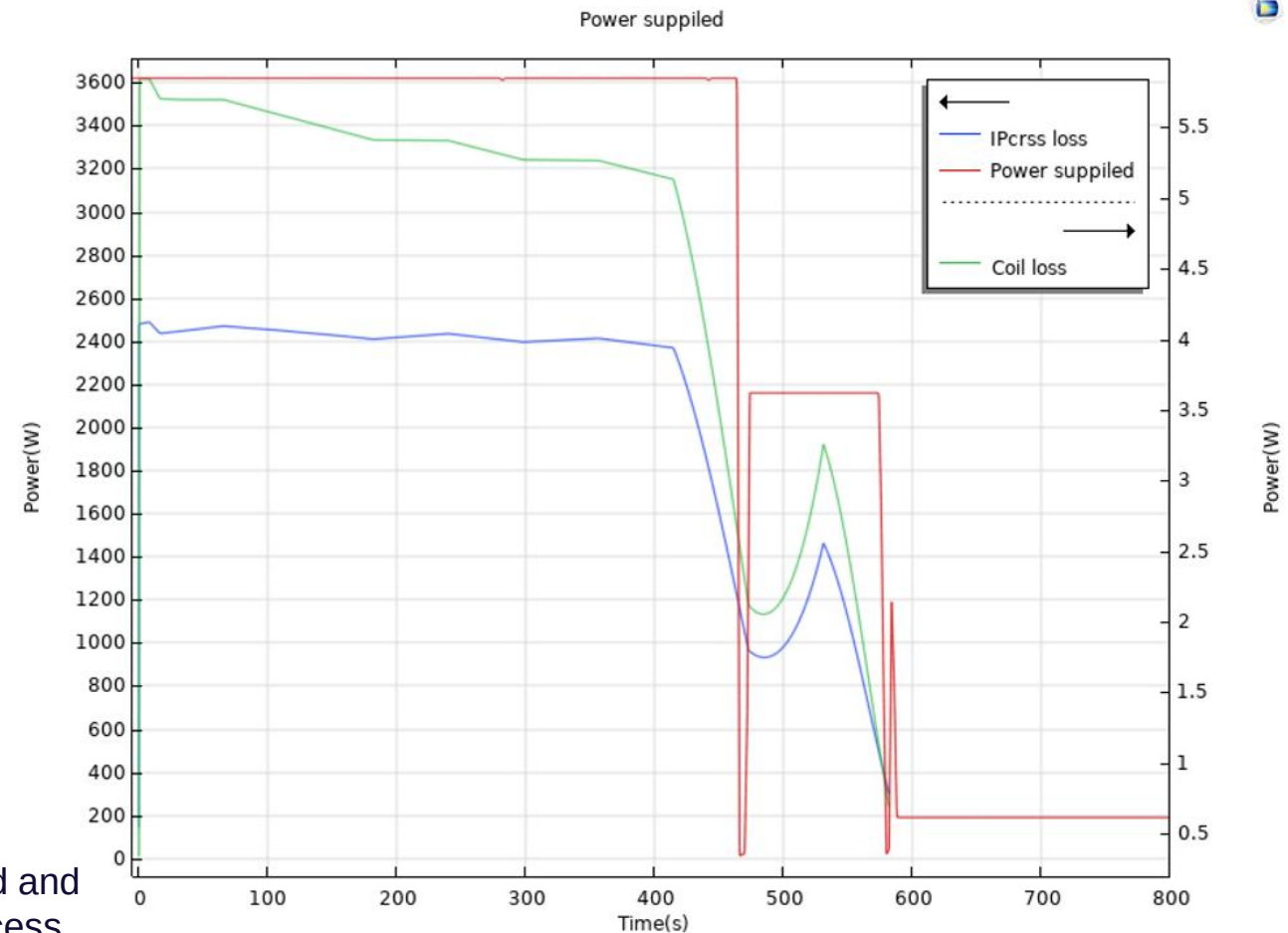
Industrial

- ✓ Reduced dependence on extensive physical testing
- ✓ Faster process development
- ✓ Greater confidence in system design decisions

Future Opportunities

- ✓ Automated coil design
- ✓ Digital process optimisation
- ✓ Reusable induction heating modelling templates

A validated COMSOL-based simulation framework was developed and applied beyond model validation to support induction-heating process development and investigate the influence of key design and operating parameters.



Thank you

Contact: heather.nute@the-mtc.org

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