SWERIM

We create benefit for industry

METALLISKA MATERIAL

GJUTERI FÖRENINGEN Swedish Foundry Association

Jernkontoret

Svenskt Aluminium

Med stöd från

VINNOVA Sveriges innovationsmyndighet

Energimyndigheten

FORMAS

Strategiska innovations-program

Modelling of induction heating in steel reheating furnaces

Ted Sjöberg - PhD

Researcher, Ted.Sjoberg@swerim.se

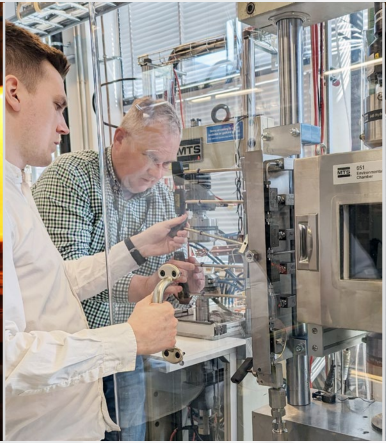
Outline

- Swerim in short
- Pilot experiments
- Simulation setup
  - Geometry
  - Physics interfaces
- Results
  - Super Duplex 2507
  - Low carbon steel
- Conclusions & next step

Swerim conducts needs-based industrial research and development concerning metals and their route from raw material to finished product.

Our vision is a fossil-free and circular industry.





Swerim in short

- Independent research institute
- Unique pilot, test and demonstration facilities (Customized experimental equipment)
- Customers from all over the world
- Long-term strategic partner
- Three research councils with industry representatives
- 190 employees
- Turnover approximately SEK 250 million

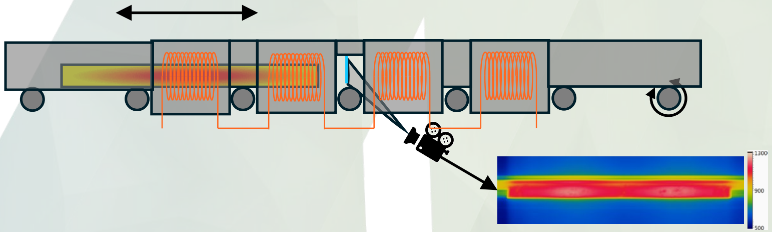
Long tradition – the oldest part established in 1921 (Metallografiska institutet) and MEFOS (1963)

SWERIM

Pilot experiments

Induction furnace

- Max power 900kW (material and shape specific)
- 4 induction coils (counter-wound)
- Frequency range 350 – 600 Hz
  - Set by capacitor bank in an IC-circuit
- Length 3.4 m
  - Ceramic inner lining
  - Hydraulic rollers for oscillation of workpieces
  - Insulated gaps and hoods at sides
- Max temperature 1300 °C
- Capacity 2.5 ton/h (20 to 1250 °C)
- Geometries
  - Workpieces 125-300 x 60-125 x 1600-1700 mm



Measurements

S type thermocouples for continuous temperature measurements

Thermographic imaging camera for scanning of workpiece sidewalls

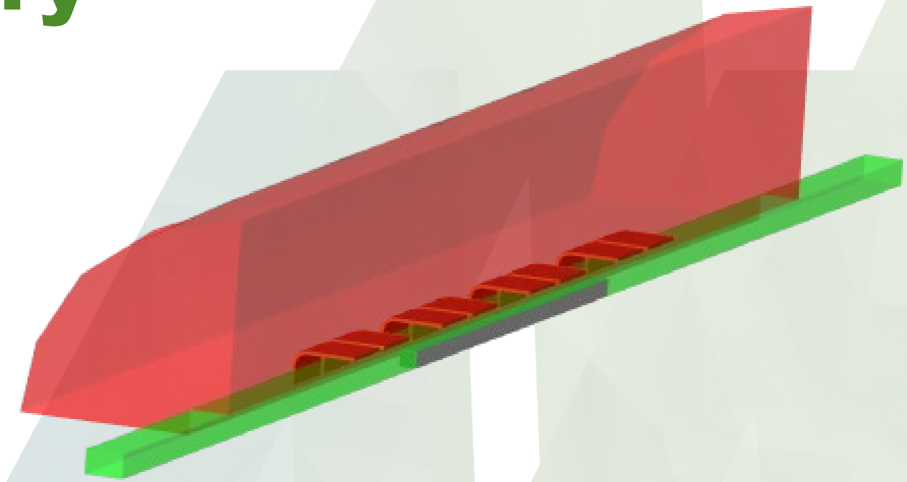
Line scanning at 10 Hz as billet travels

SWERIM

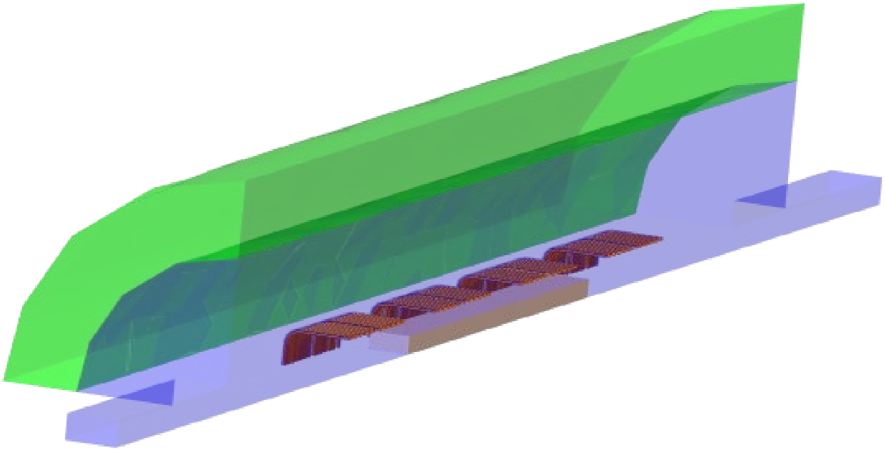
Simulation geometry

- Four coil pairs
  - 24 turns per pair

    12 turns + 12 turns reverse
- Quarter symmetric geometry
- Two-part air domain
  - Stationary red domain
  - Oscillating green domain



Simulation setup
Magnetic fields



- Rectangular workpiece
  - Simple relative permeability

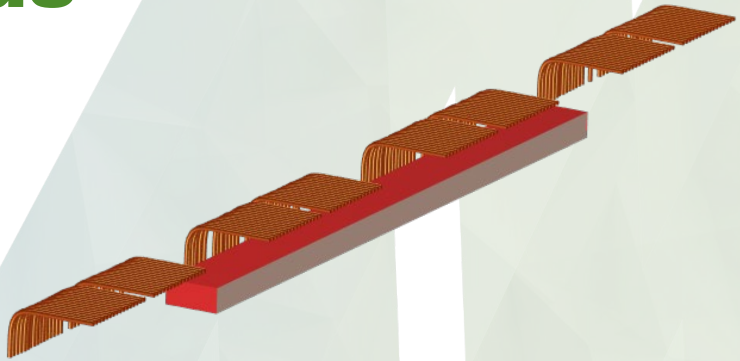
    $$B = \mu_0 \mu_r(B, T) H$$

  - Temperature dependent conductivity
- Two air domains
  - Stationary + Moving
- Eight coils
  - Homogenized multiturn
  - External coil excitation using circuit voltage
- Infinite Element Domain

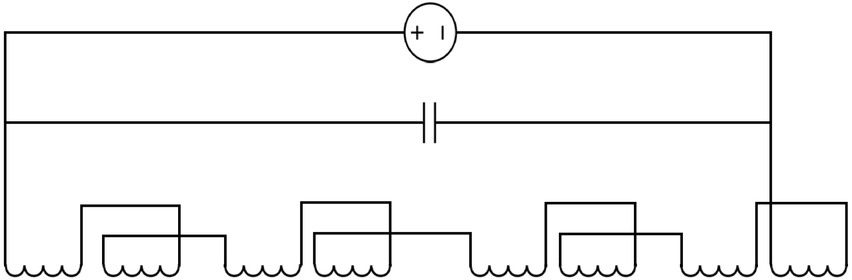
Simulation setup
Heat transfer in solids

- Temperature dependent material parameters
  - Thermal conductivity
  - Heat capacity

- Simple boundary conditions
  - Constant heat flux
  - Constant surface-to-ambient radiation
  - Symmetry



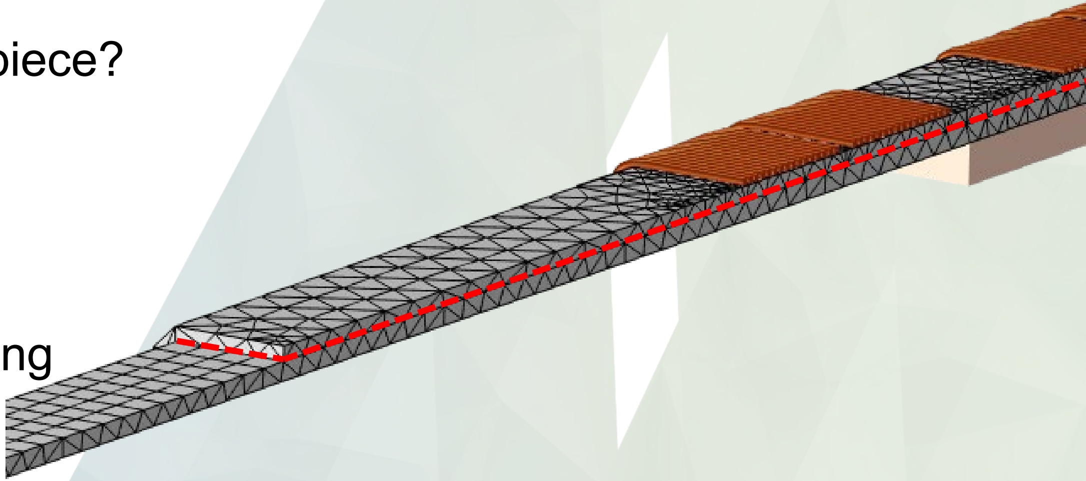
Simulation setup
Electrical circuit



- Model behaviour of resonant circuit
  - Coils “External U vs I”
  - Capacitor bank
  - Voltage source
- Idealized circuit, no resistive losses

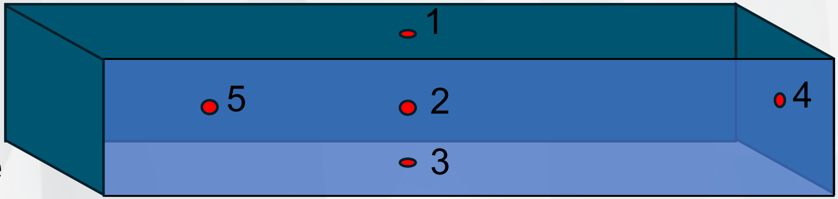
Simulation setup
Moving mesh

- How to model oscillating workpiece?
  - ~~Deforming mesh~~
  - Moving mesh
    - Retain continuity
    - Reasonable time-stepping
- Discrete stepping
  - Step size chosen to retain mesh continuity

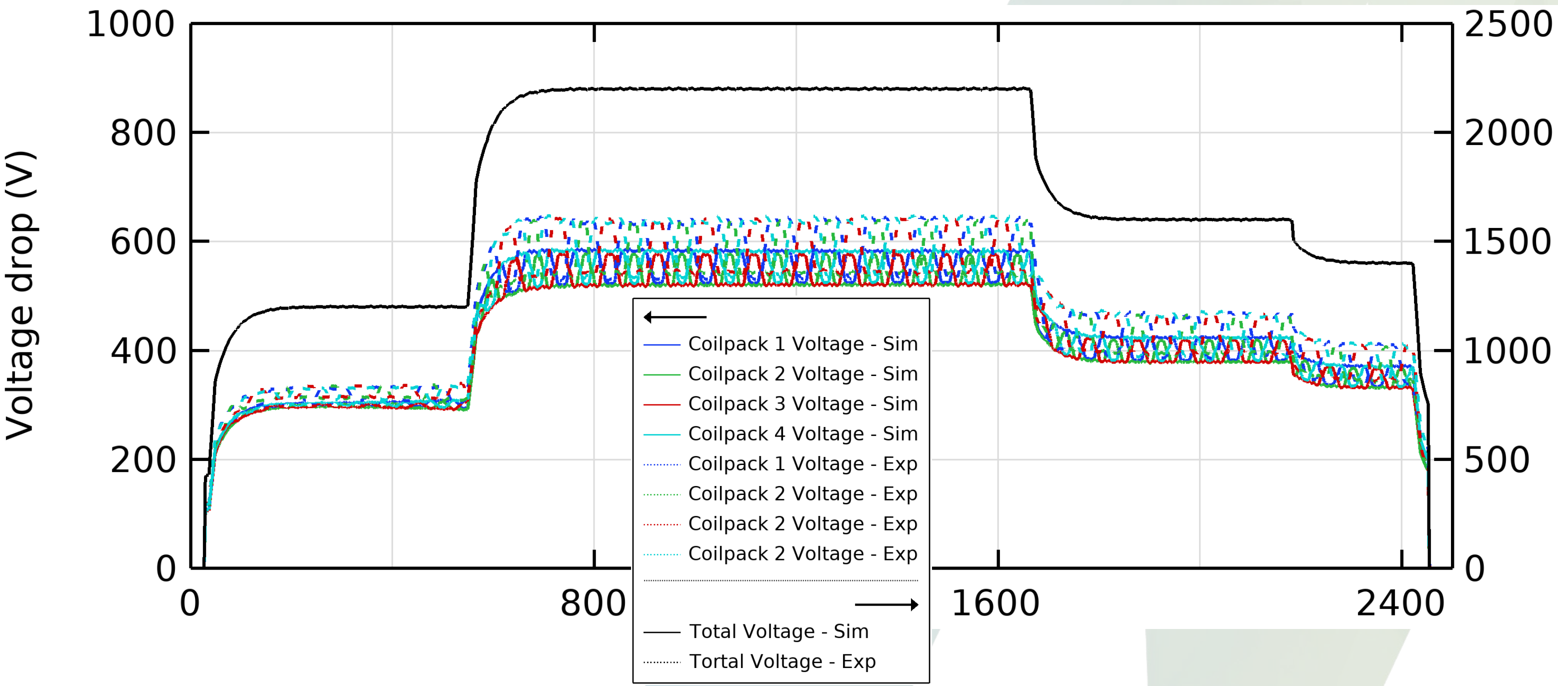


Results

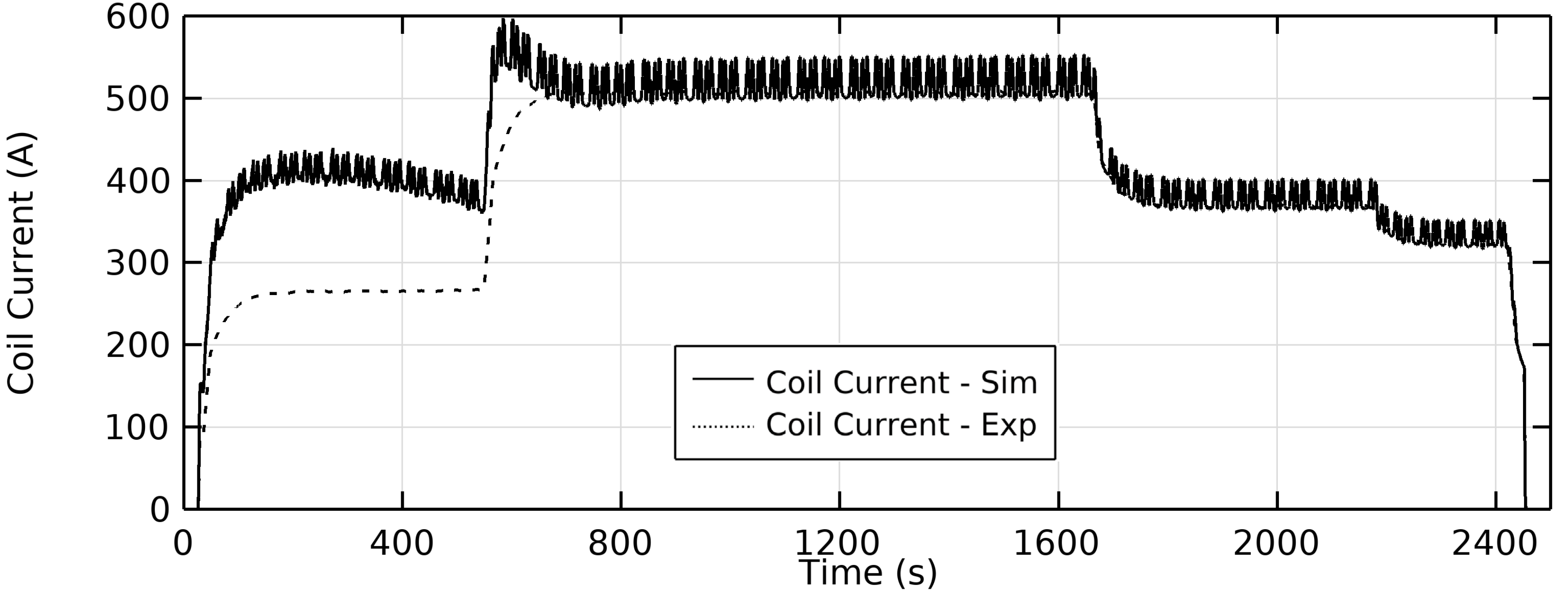
- Pilot experiment workpiece was equipped with thermocouples
- Thermal imaging was used along one side of workpiece
- Pilot induction furnace is equipped with multiple measurement systems
  - Coils: power, current, voltage drop
  - Cooling water in- & outgoing temperature



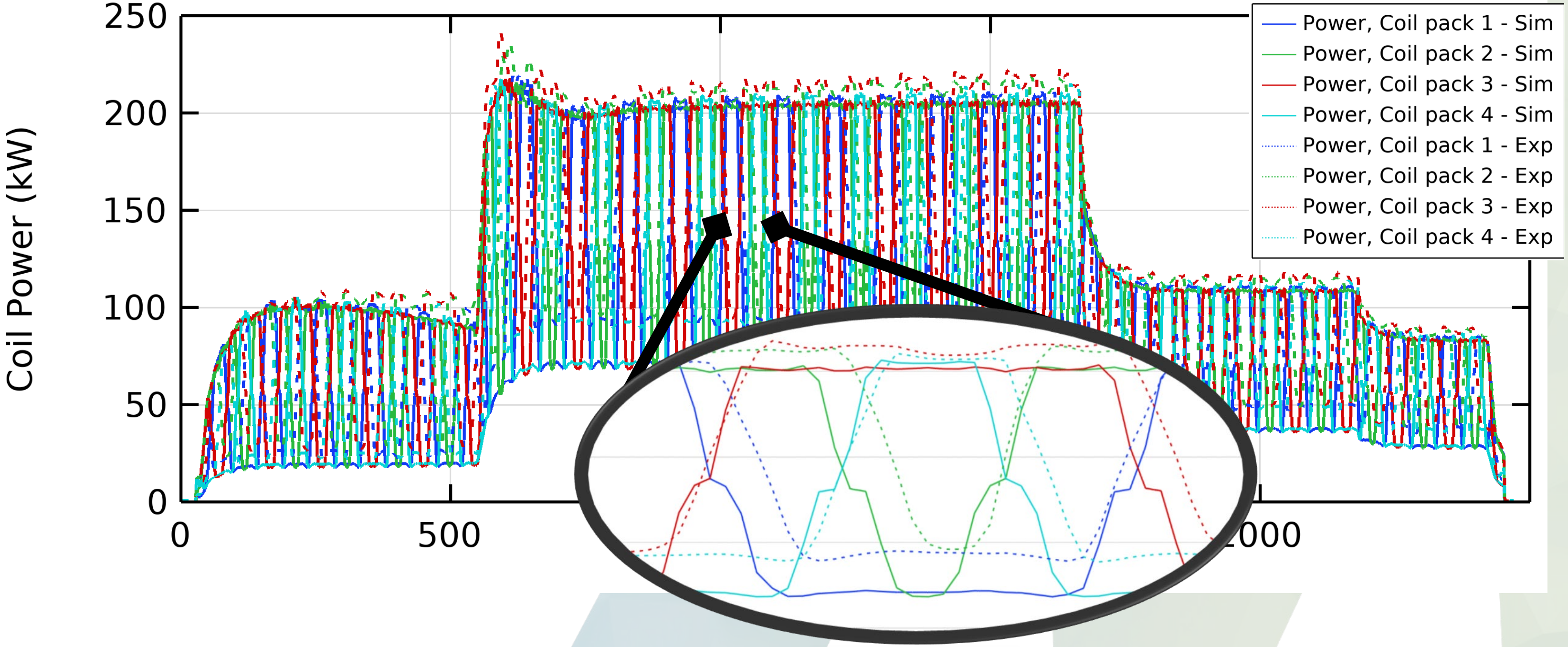
Results - Super Duplex 2507
Coil voltage drop



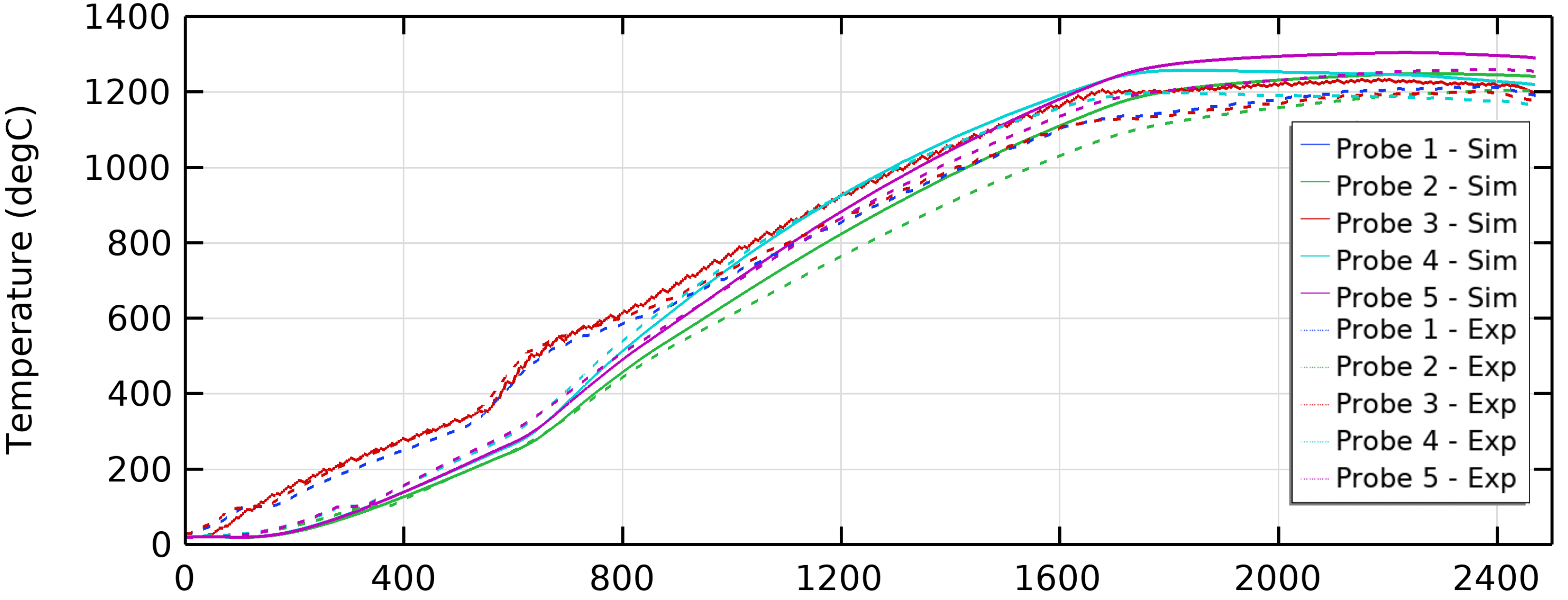
Results - Super Duplex 2507
Coil current



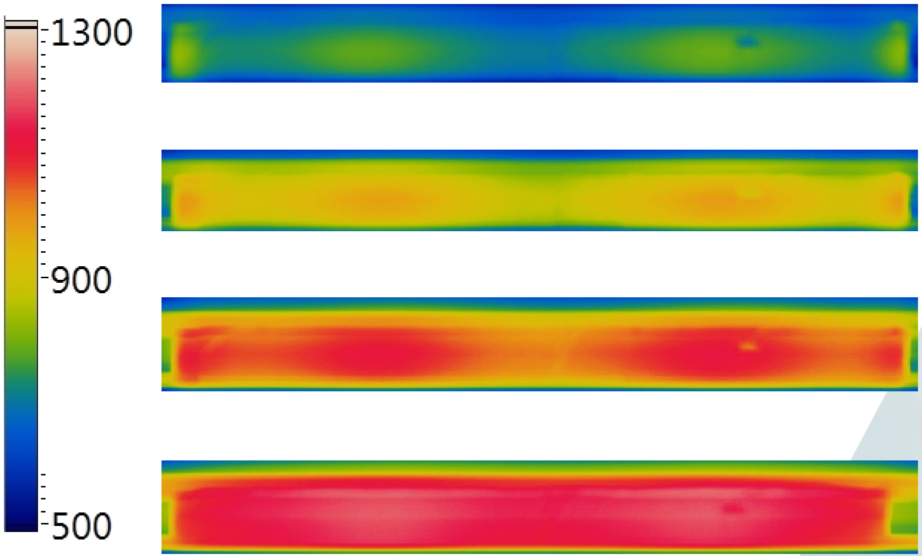
Results - Super Duplex 2507
Coil power

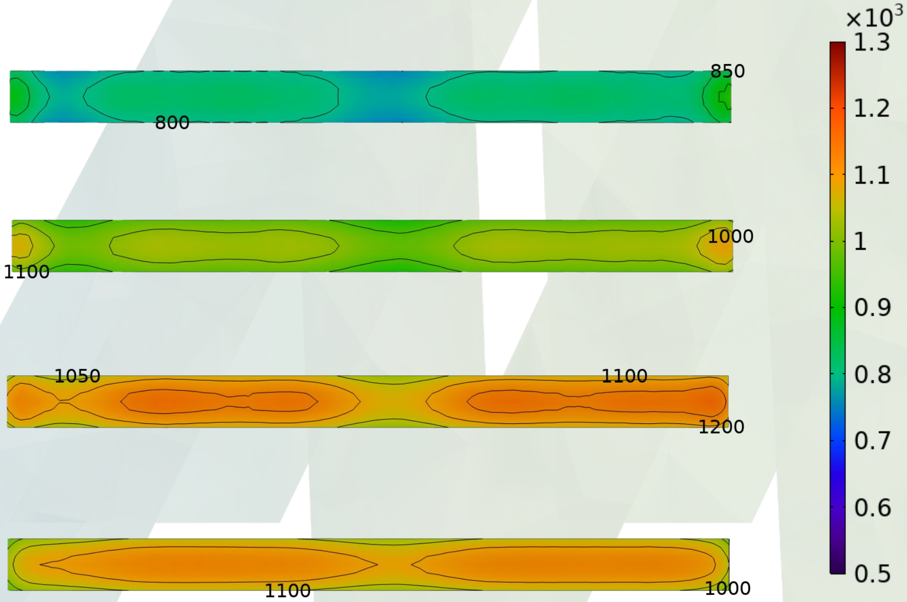


Results - Super Duplex 2507
Heating rate

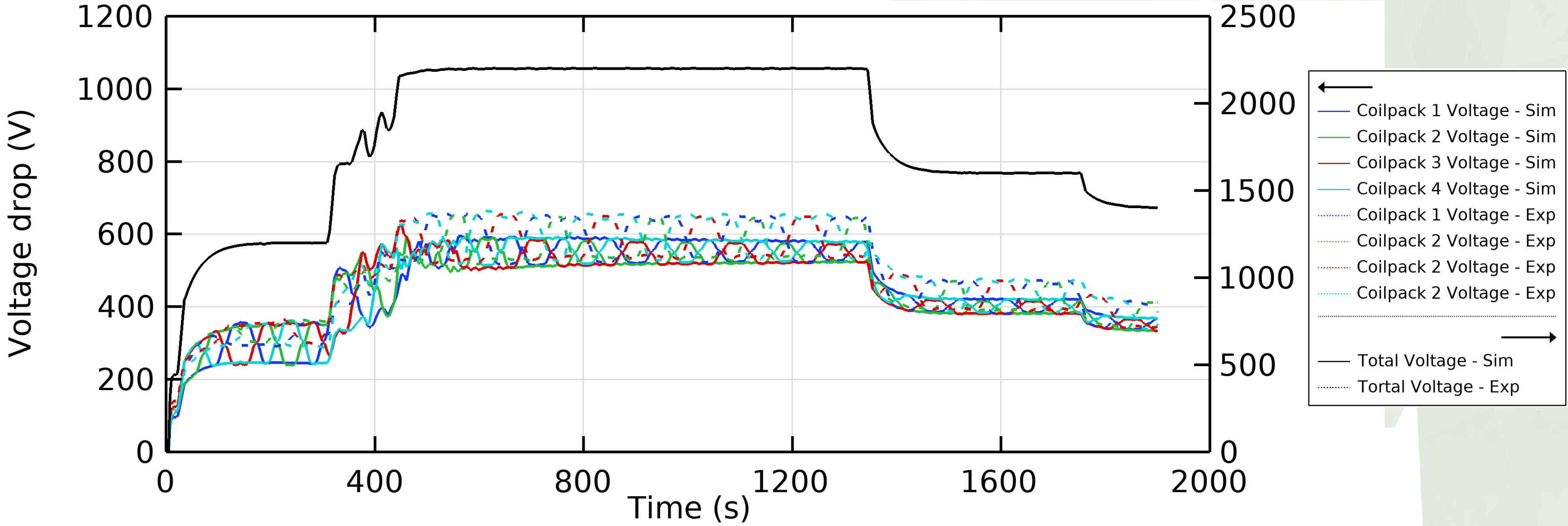


Results - Super Duplex 2507 Temperature

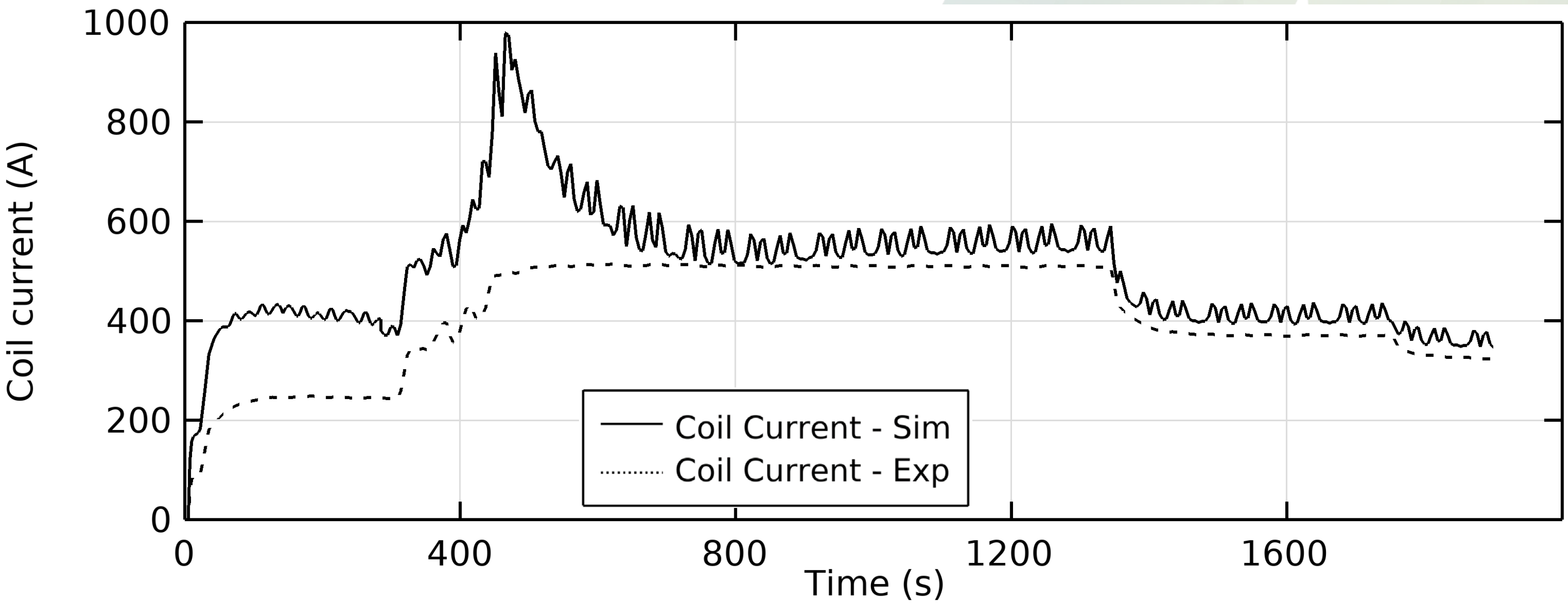




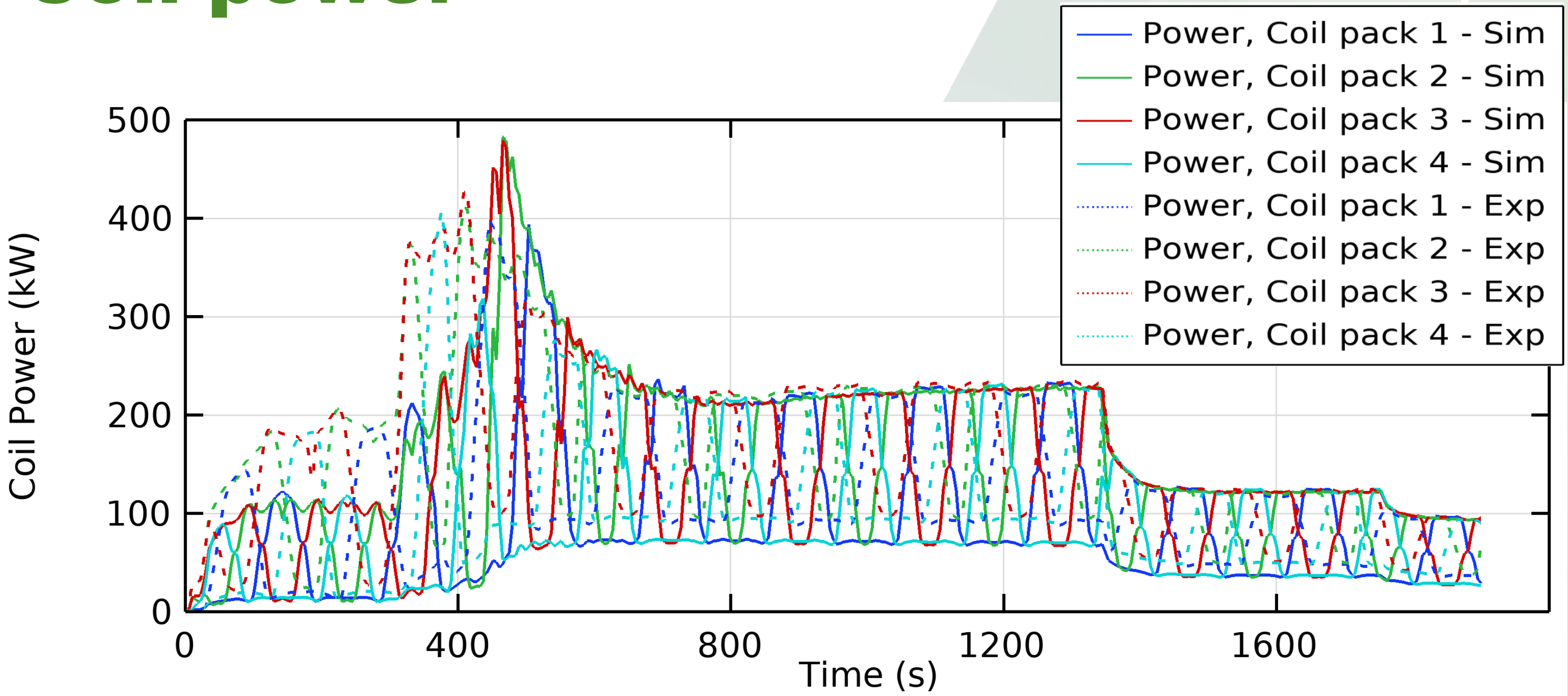
Results – Low-alloyed steel
Coil voltage drop



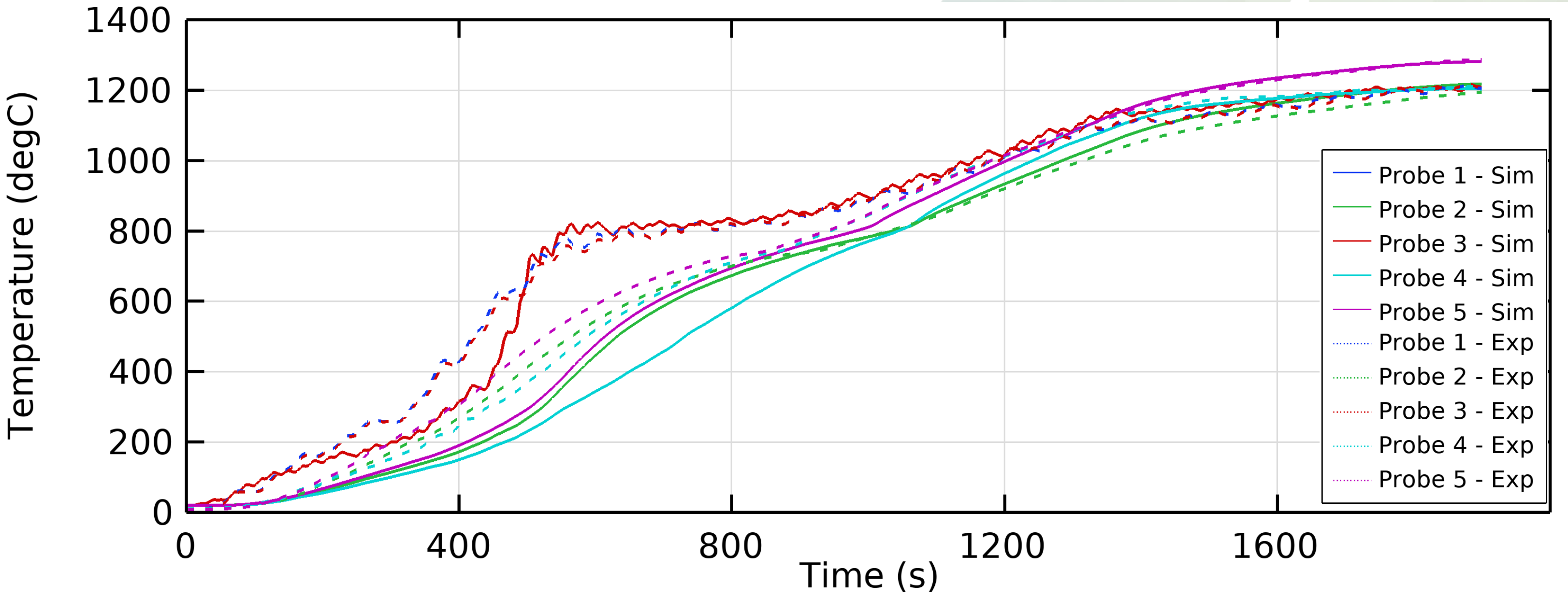
Results - Low-alloyed steel
Coil current



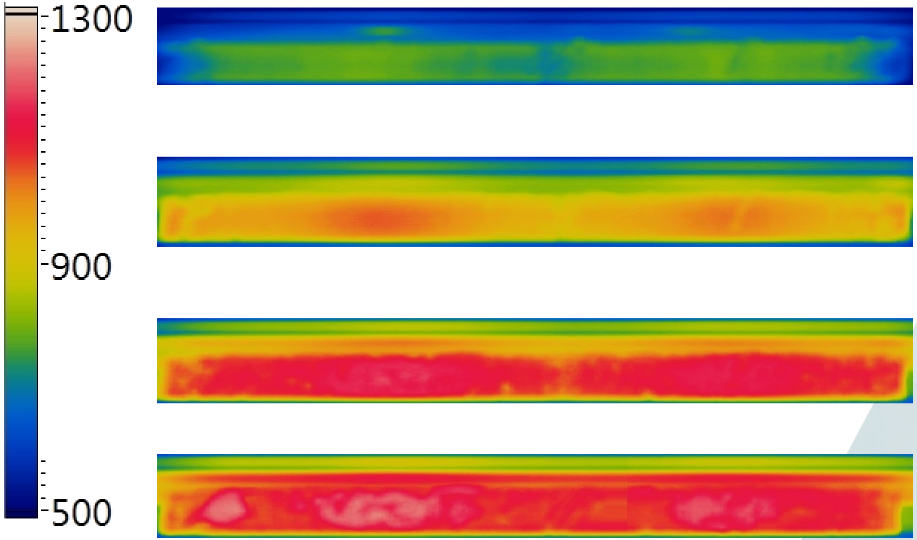
Results - Low-alloyed steel
Coil power

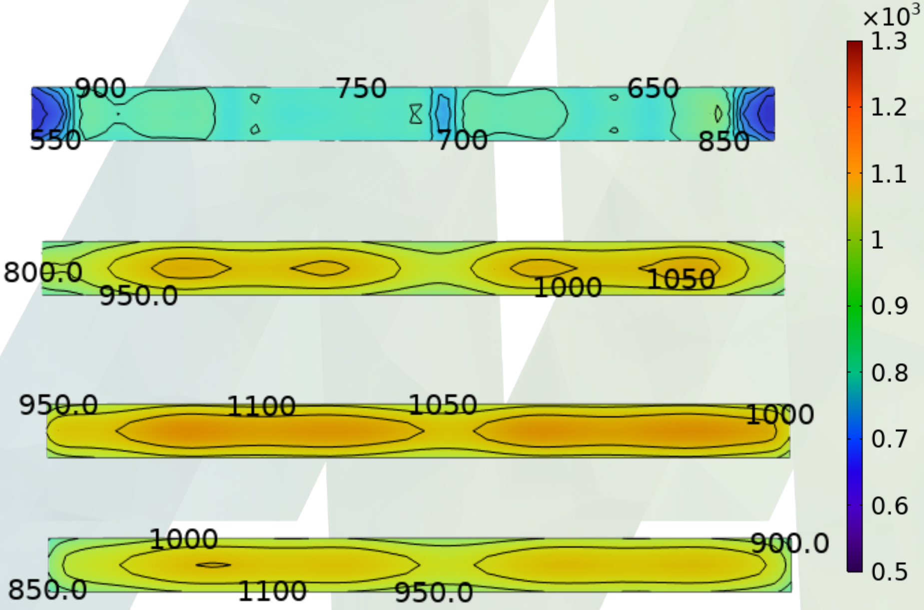


Results - Low-alloyed steel Heating rate



Results – Low-alloyed steel Temperature





Conclusions and future work

- Used simple material models work well and give reasonable results
- Moving workpiece is simulated well using discrete stepping with conforming mesh
- Simulation of LC-circuit yields satisfactory results when compared to measurements from experiments

- Further improvement of thermal boundary conditions could increase simulation accuracy
- Simulations of more, different experiments could prove interesting.
  - Differing oscillation velocity
  - Differing coil frequency
  - More material grades

DET STRATEGISKA INNOVATIONSPROGRAMMET

METALLISKA MATERIAL

METALLISKA MATERIAL
GJUTERI FÖRENINGEN
Jernkontoret
Svenskt Aluminium

Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

SWERIM

We create benefit for industry

Ted.Sjoberg@Swerim.se