International Symposium on Heating by Electromagnetic Sources

Improving Induction Tube Welding System Performance Utilizing Soft Magnetic Composites

May 23rd 2019

Background

- Inductive welding is a popular method for making tubes used in a variety of industries
- Induction Tube Welding Process involves:
  - Rolls of steel strip are run through forming mills to create the tube shape with a closing seam
  - An inductor is used to heat the inside edges of this seam
  - The softened tube edges are squeezed together by the closing rolls to form a solid state weld

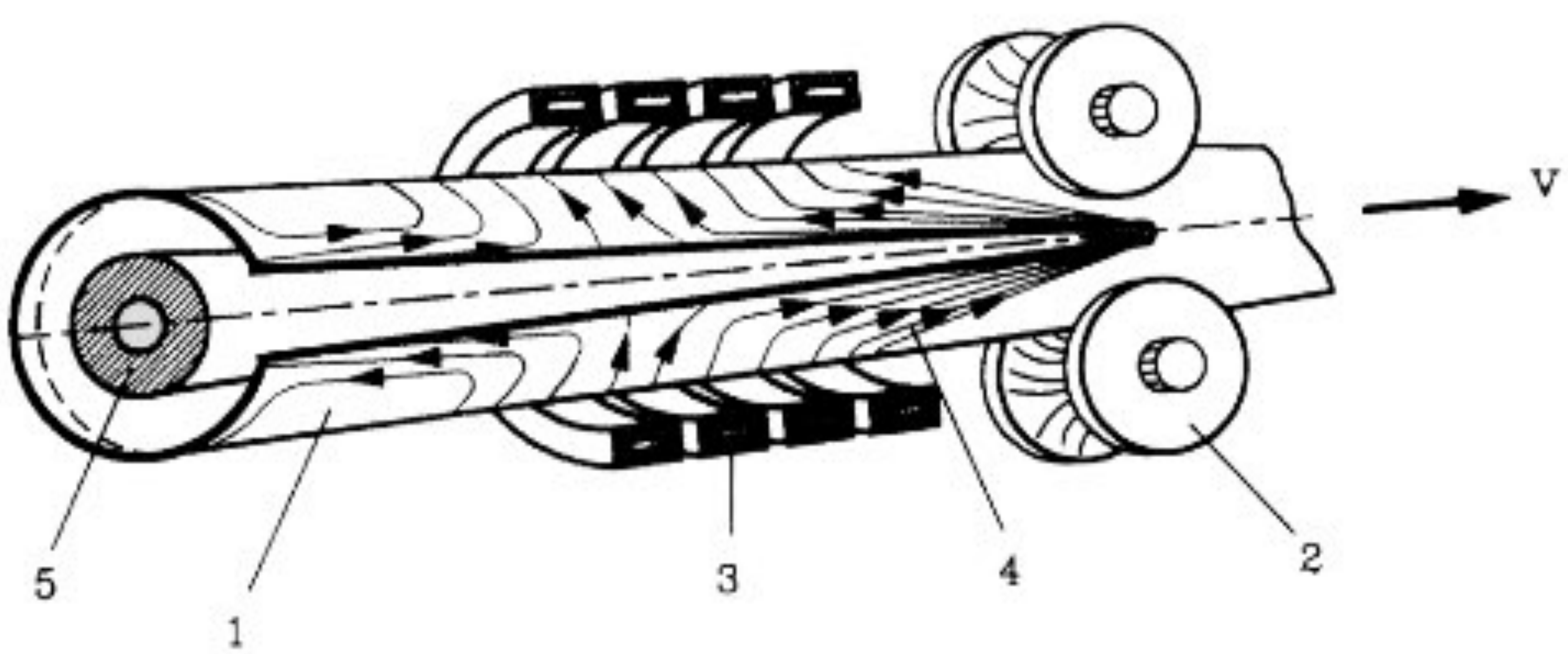


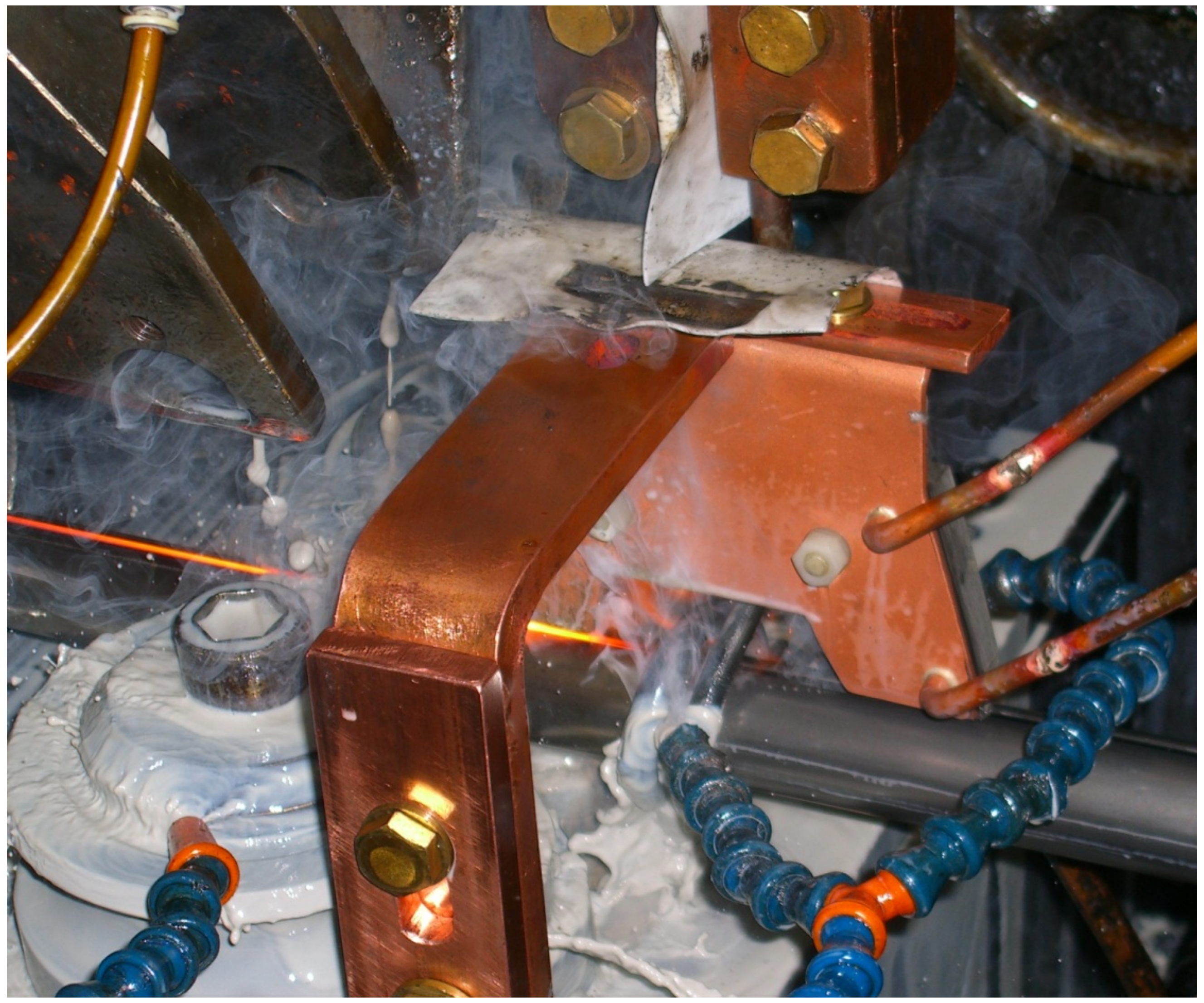
Image taken from UIE book "Induction Heating – Industrial Applications"

Industry Trends

- The industry has been transitioning from tube generators operating at 400 kHz, to more efficient solid state generators, which operate at frequencies from 50 kHz to 400 kHz
- The availability of high power at lower frequencies has created the opportunity to successfully weld tubes with greater wall thicknesses or more challenging alloys for more demanding applications
- At the same time, one of the key components of the system, the impeder, has not changed significantly, which is limiting the production rate or resulting quality of some types of tubing

Magnetic Flux Controllers in Tube Welding Systems

- Magnetic flux concentrators are utilized in this system to increase system performance and product quality
- Magnetic flux controllers are commonly used on the inside of the pipe as shown and called an “impeder”
- More recent publications have shown the potential for magnetic flux controllers to be used on the outside of the tube, which was called the “magnetic bridge” by Prof. Nemkov



Welding Process with Magnetic Bridge

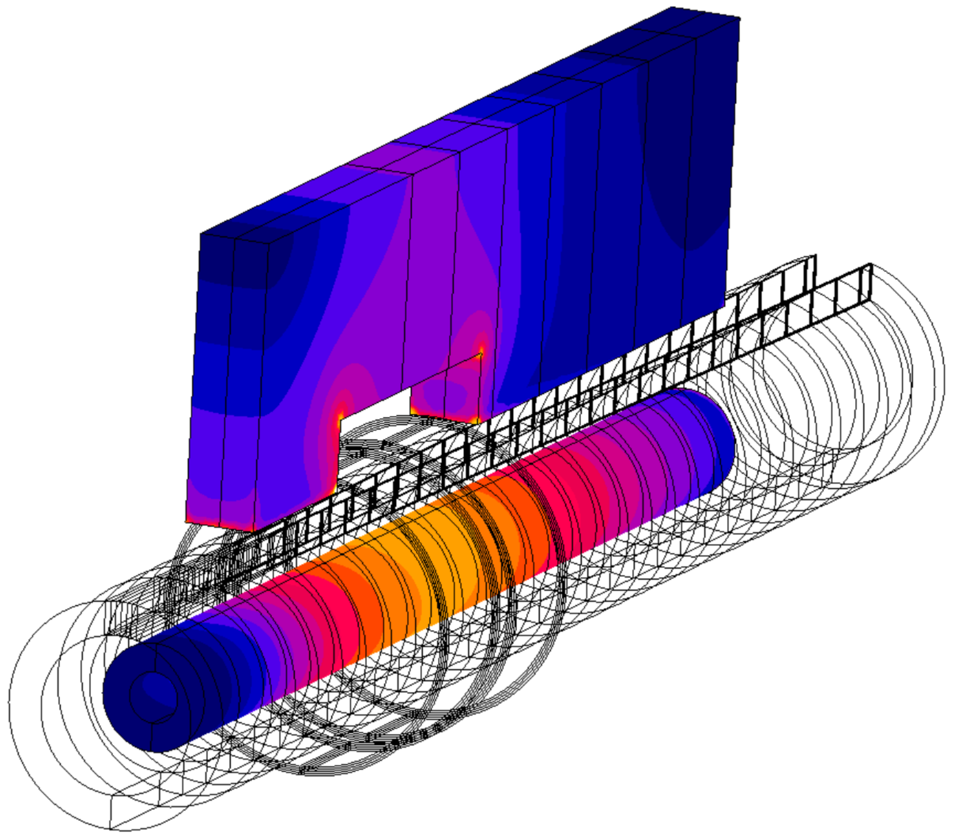
Impeder Background

- Impeders are typically manufactured using a combination of constructive elements and ferrite rods or tubes(ferrites)
- The ferrites have low saturation flux density which is strongly temperature sensitive
- The saturation flux density becomes more and more of an issue for lower frequencies
- This new situation creates an opportunity to improve the welding system performance using soft magnetic composite materials (SMCs)

https://www.efd-induction.com/en/induction-heating-equipment/weldac-tube-welder

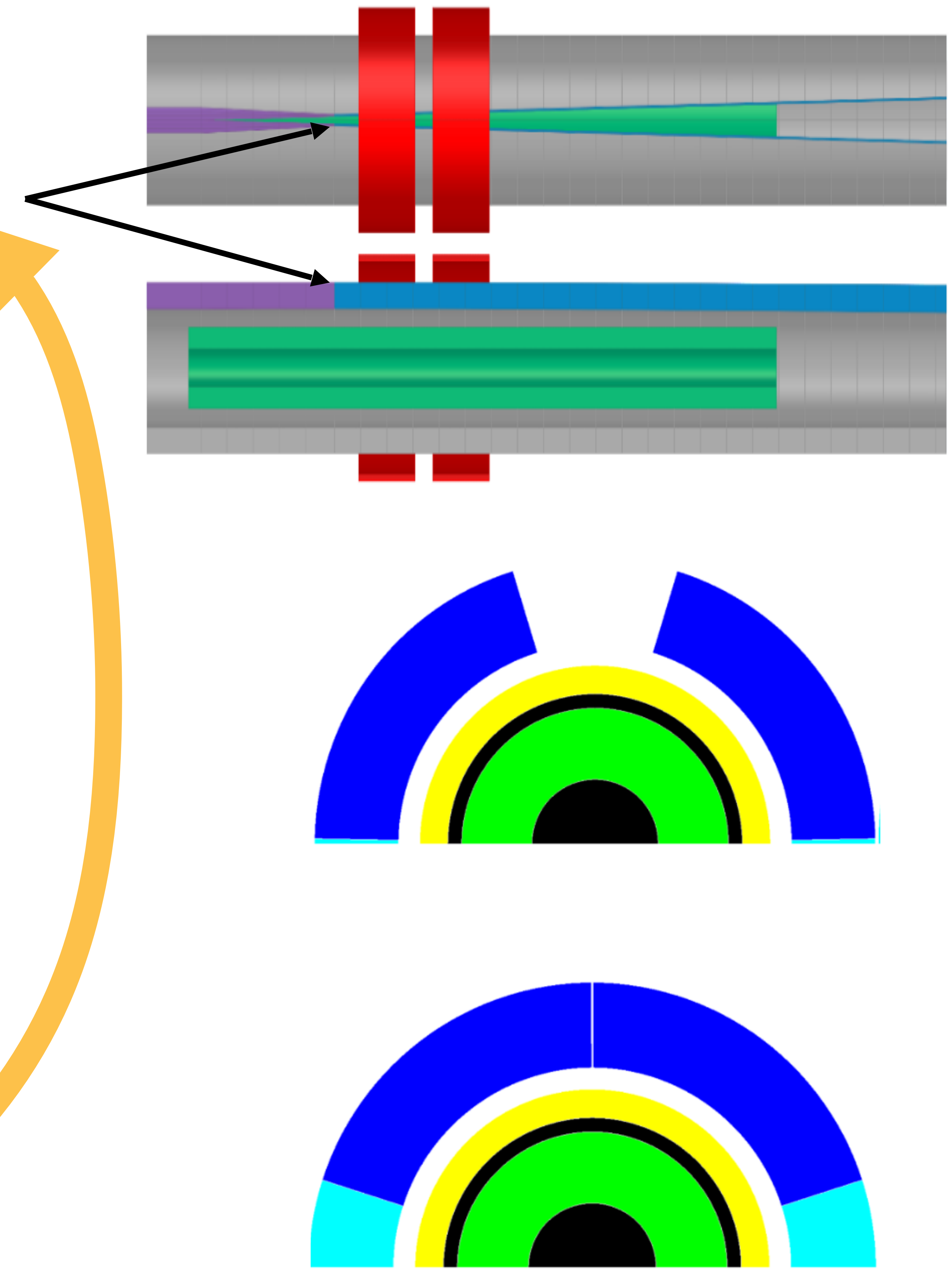
Computer Simulation

- The use of 2-D models for studying the temperature distribution in the weld vee started in the late 1990s (Asperheim, et. al)
  - Fast, but limited accuracy
- Recently, several publications have been made on the use of advanced 3-D coupled models
  - Great potential accuracy, but very time consuming
- In this paper, a new hybrid method utilizing a combination of 2-D and 3-D coupled models will be used
  - Good speed, Good potential accuracy



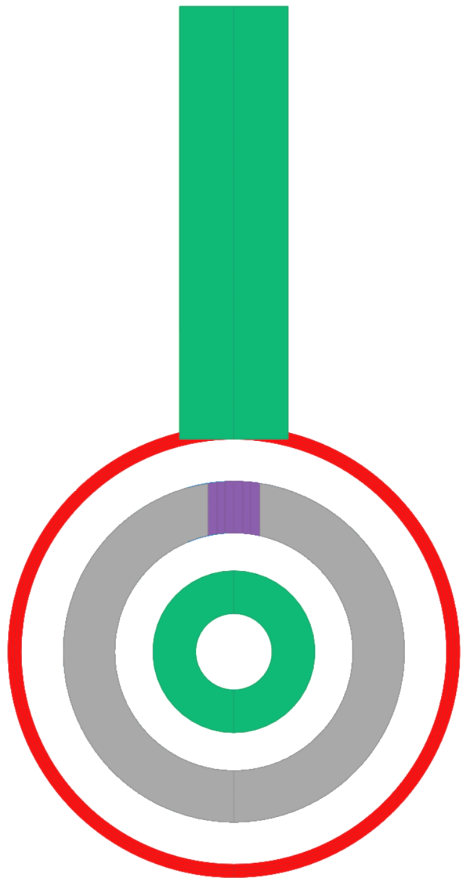
Case Study Geometry

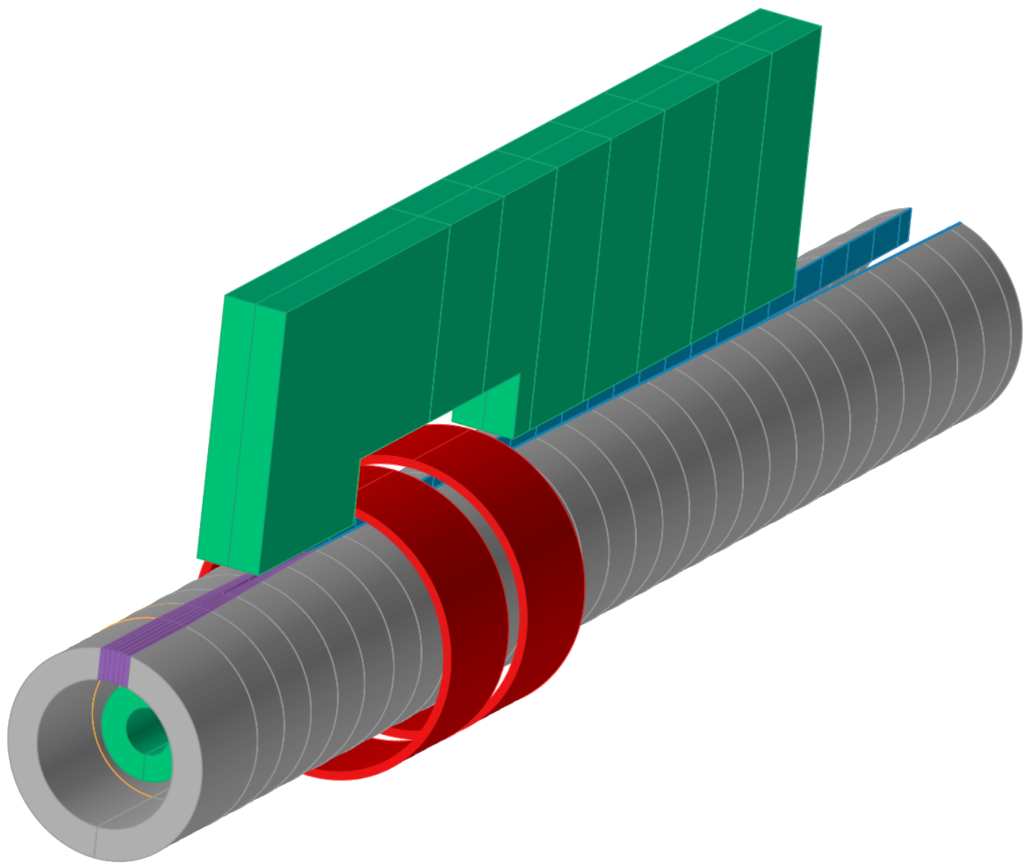
- Run 3-D EM Model with Assumed Magnetic to Non-Magnetic Transition Point
- Export Z-component of Current vs. Length of Tube to 2-D Model
- Use 2-D coupled model with rotation to determine temperature vs. position
- Adjust Current Level to Achieve Proper Temperature
- Adjust 3D model



Case Study Conditions

- Steel Tube:
  - 40 mm OD with 6 mm wall thickness
- 2° weld vee angle
- Inductor:
  - two-turns
  - 50 mm ID, 50 mm length
  - 60mm from the end of the coil to the apex
- Impeder:
  - 19 mm OD, 9 mm ID
  - 225 mm length
- Magnetic Bridge

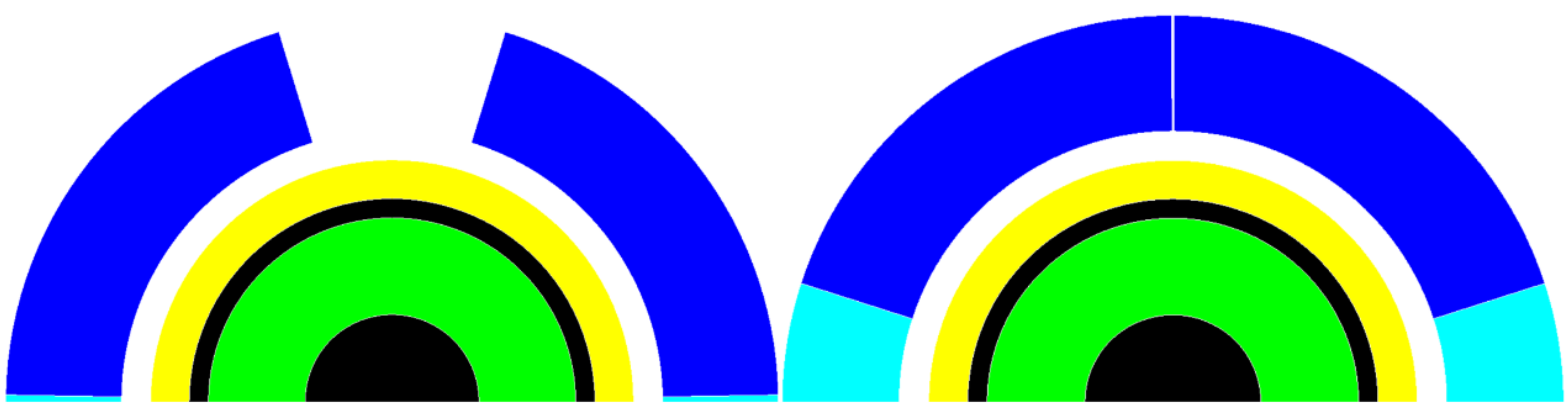




Case Study Geometry

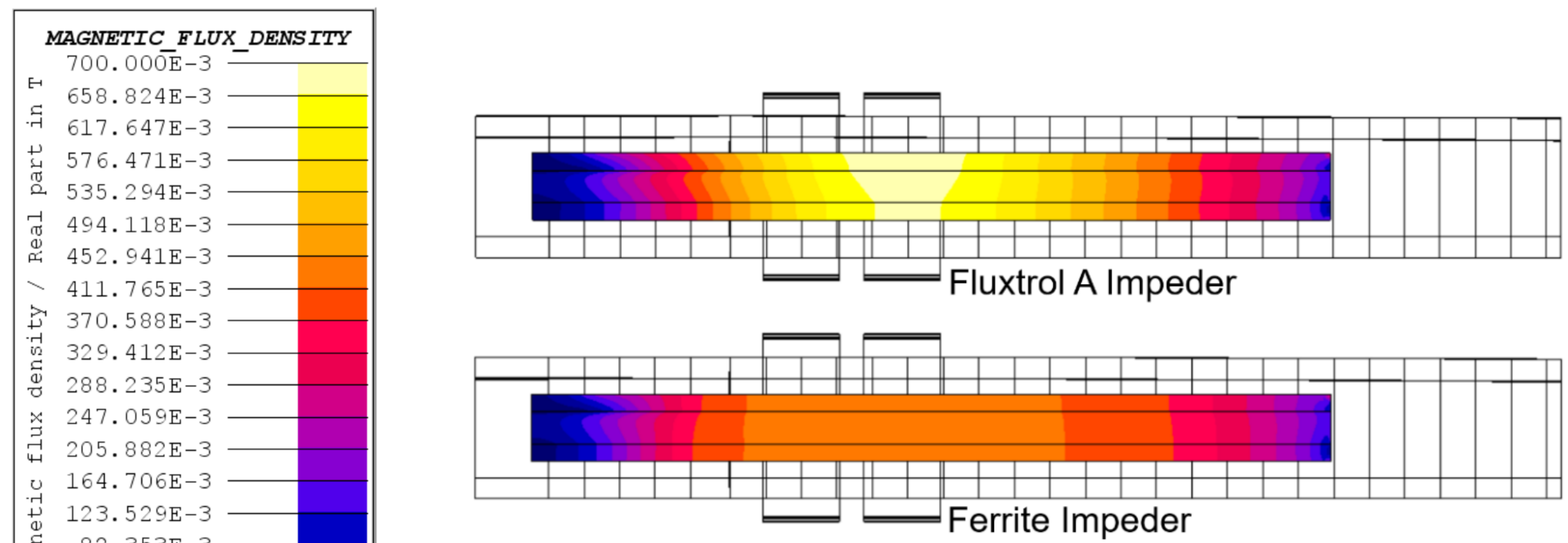
- Line speed is 20 m/min
- Frequency 200 kHz
- Minimum Temperature On Edge Surface 900 C

- Comparison Made Between
  - Ferrite Impeder (standard)
  - Fluxtrol A Impeder
  - Fluxtrol A Magnetic Bridge with Ferrite Impeder
  - Fluxtrol A Magnetic Bridge with Fluxtrol A Impeder

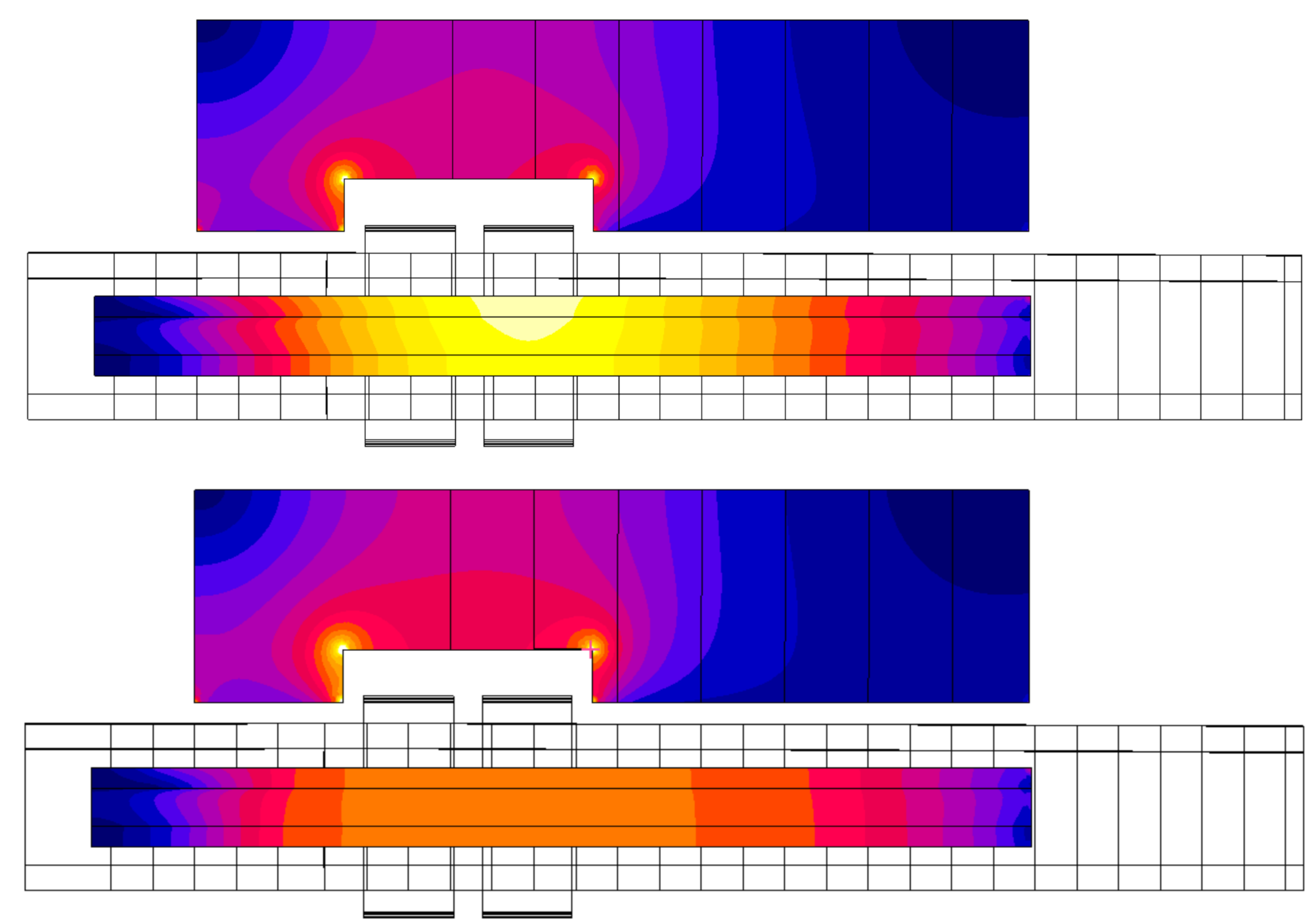


Magnetic Flux Density Distribution in MFC's

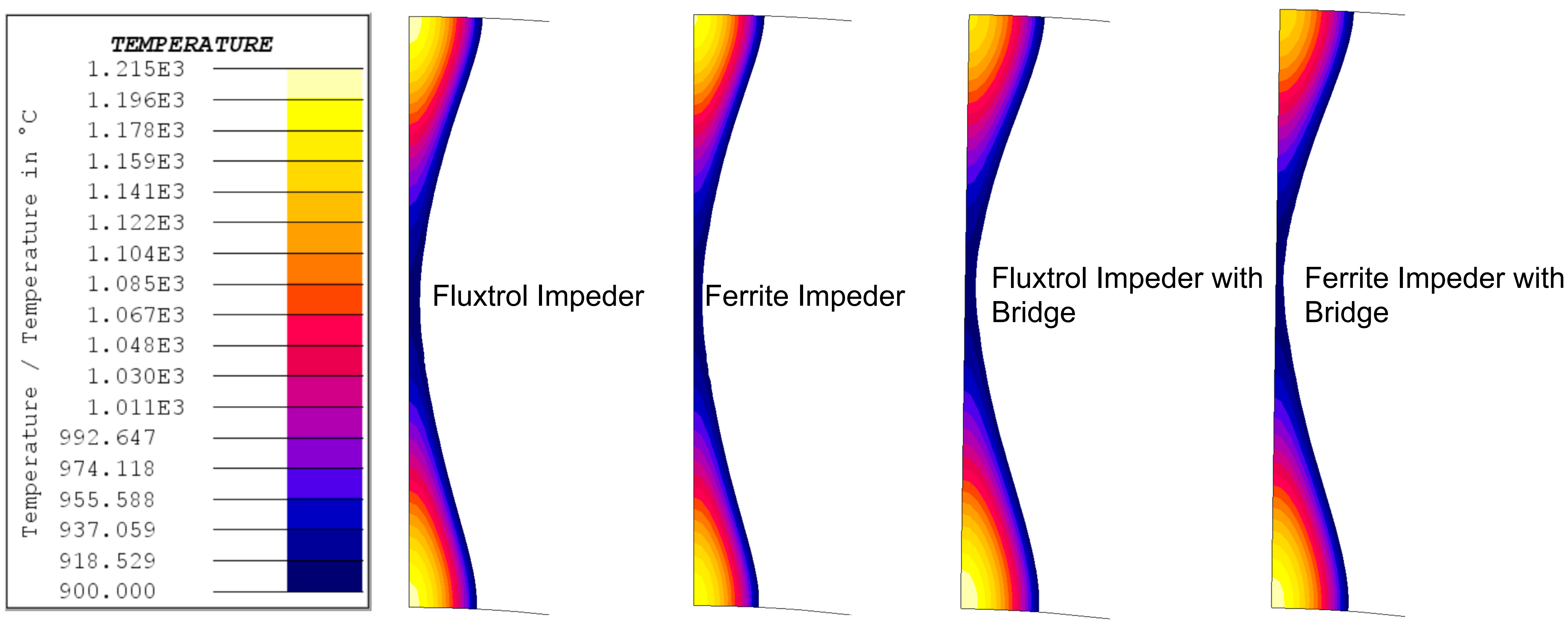
- Fluxtrol A is well below its saturation
- Ferrite heavily saturated



- The addition of the bridge partially reduces flux density in the impeder

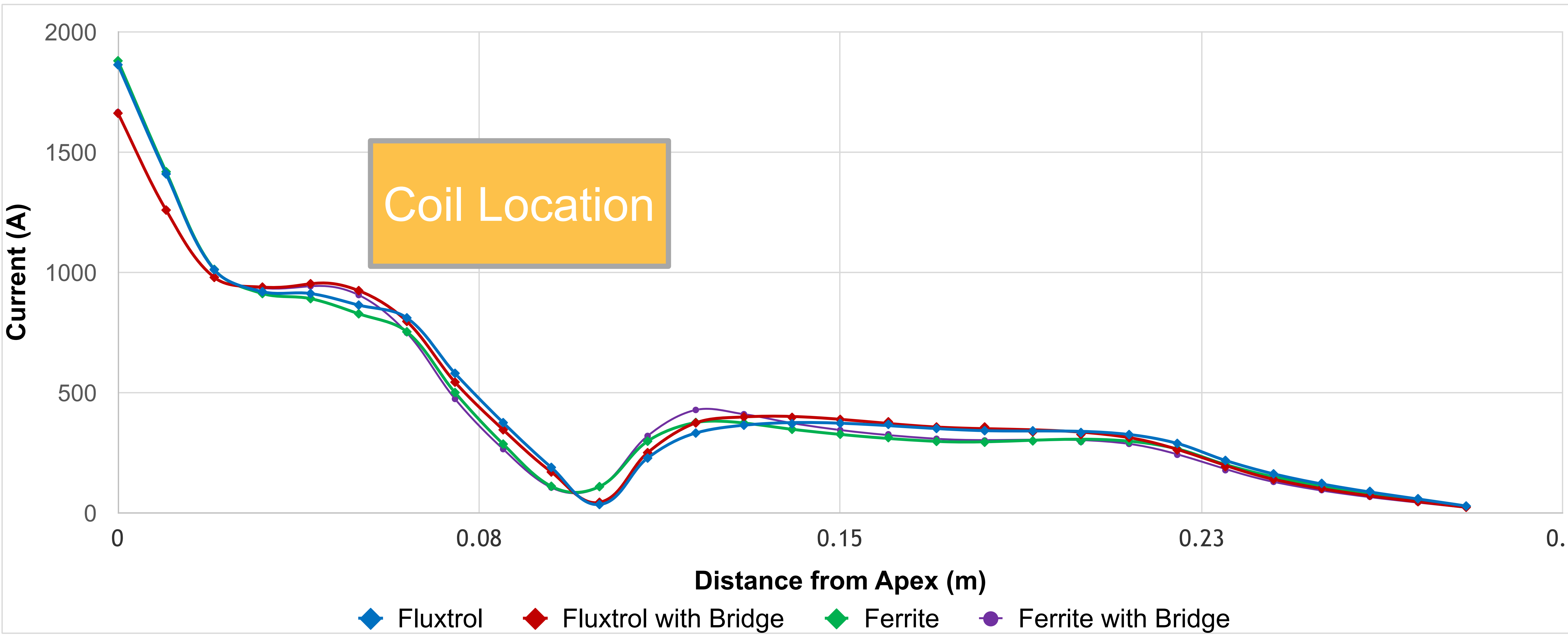


Temperature Distributions



- Temperature distributions similar for Fluxtrol A and Ferrite Impeder
- Magnetic bridge lowers OD surface temperature
  - This is due to reduction in electromagnetic end effect, leading to reduced current required to reach equivalent temperature in the center of the tube

Current Along The Weld Vee



- The main concentrations of current density are along the edge of the weld vee leading towards the apex
- The current density along the edge of the weld vee going back towards the incoming material is smaller than going to the apex, but still significant

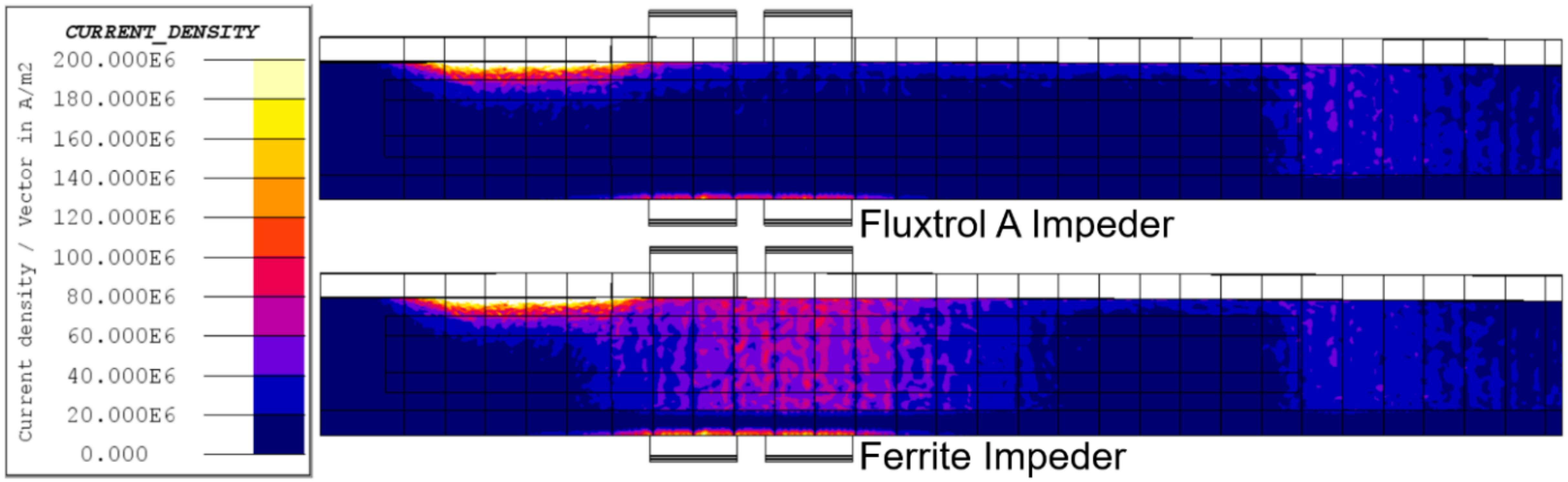
Simulation Results

Impeder	Current (A)	Coil Power (kW)	Weld Vee T_{Min} (°C)	Weld Vee T_{Max} (°C)
Fluxtrol A	1800	73	915	1205
Ferrite	2400	82	910	1197
Fluxtrol A With Bridge	1500	67	912	1213
Ferrite With Bridge	2050	76	906	1207

- Using an impeder made of Fluxtrol A compared to a traditional Ferrite results in a significantly lower required coil current and coil power
- Adding a Bridge has a similar effect, further reducing coil currents and coil head power

* - Coil Head Power only includes losses in the coil winding and tube and does not include any losses in power delivery components or coil leads, which should be proportional to current squared

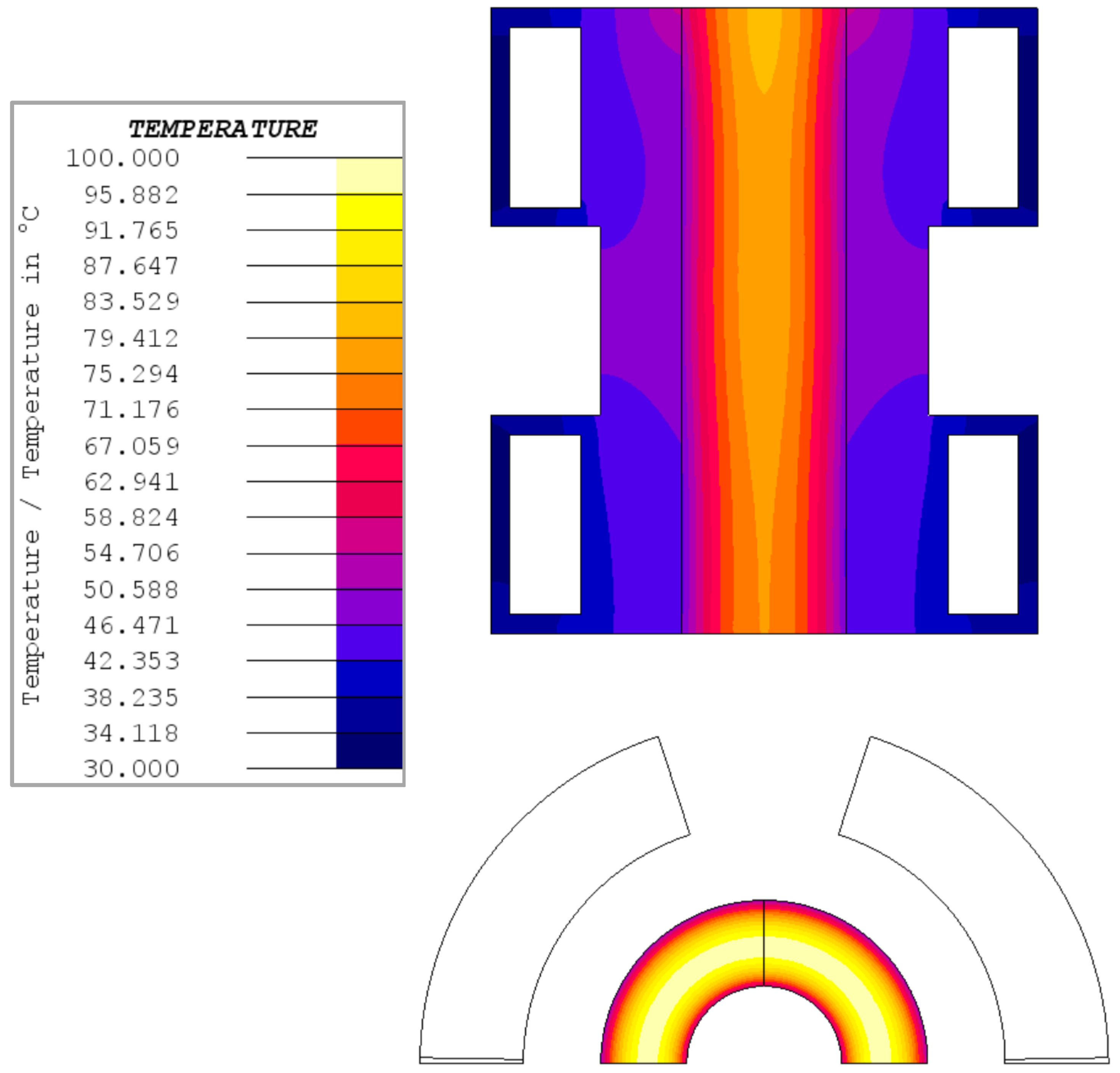
Current Density on the ID



- Once the ferrite reaches saturation, some current begins to flow around the ID of the tube as opposed to along the edges of the weld vee
- This additional current density is how we can explain the higher current required using the ferrite impeder as compared to the Fluxtrol A impeder
- Another band of current can be seen flowing on the ID of the tube after the end of the impeder

Fluxtrol Cooling

- Fluxtrol A does have higher magnetic losses than ferrites
- These losses are not significant to the overall process efficiency
- However, it means proper water cooling is required to ensure good longevity
- To ensure proper continuous use, a maximum operating temperature of 250°C should not be exceeded within the impeder or bridge
- Assuming a cooling water inlet of 60PSI at 30°C both the impeder and bridge can be cooled



Conclusions

- In many tube welding applications, ferrite impeders are saturated
- The lower the frequency, faster the line speed, or higher the ratio of wall thickness to tube diameter, the greater the likelihood that the ferrite is saturated
- In systems where the ferrites are saturated, Fluxtrol A material has the potential to significantly improve the system performance
- The most notable improvements when switching from ferrite to Fluxtrol A are a reduction in required inductor current and in required system power for the same welding speed
- The system performance (either with ferrites or Fluxtrol A) can be further improved using a magnetic bridge

Future Work

- Work is currently underway to validate the new modelling technique with real world data
  - Run Trials in real tube welding mills on various tube sizes, production rates, impeder and magnetic bridge designs are planned during 2019
  - Updates to the models will be made based upon the field data and presented at future events
- Plans for 2019 are to improve the 2-D simulation to consider variation in magnetic permeability in the length of the impeder and adding conductive components of the impeder and bridge assembly to the 3-D model

Questions

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