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Simulation and Modelling to Validate SMC Impeder Performance

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IMAT ASM'S ANNUAL MEETING

INTERNATIONAL MATERIALS, APPLICATIONS & TECHNOLOGIES

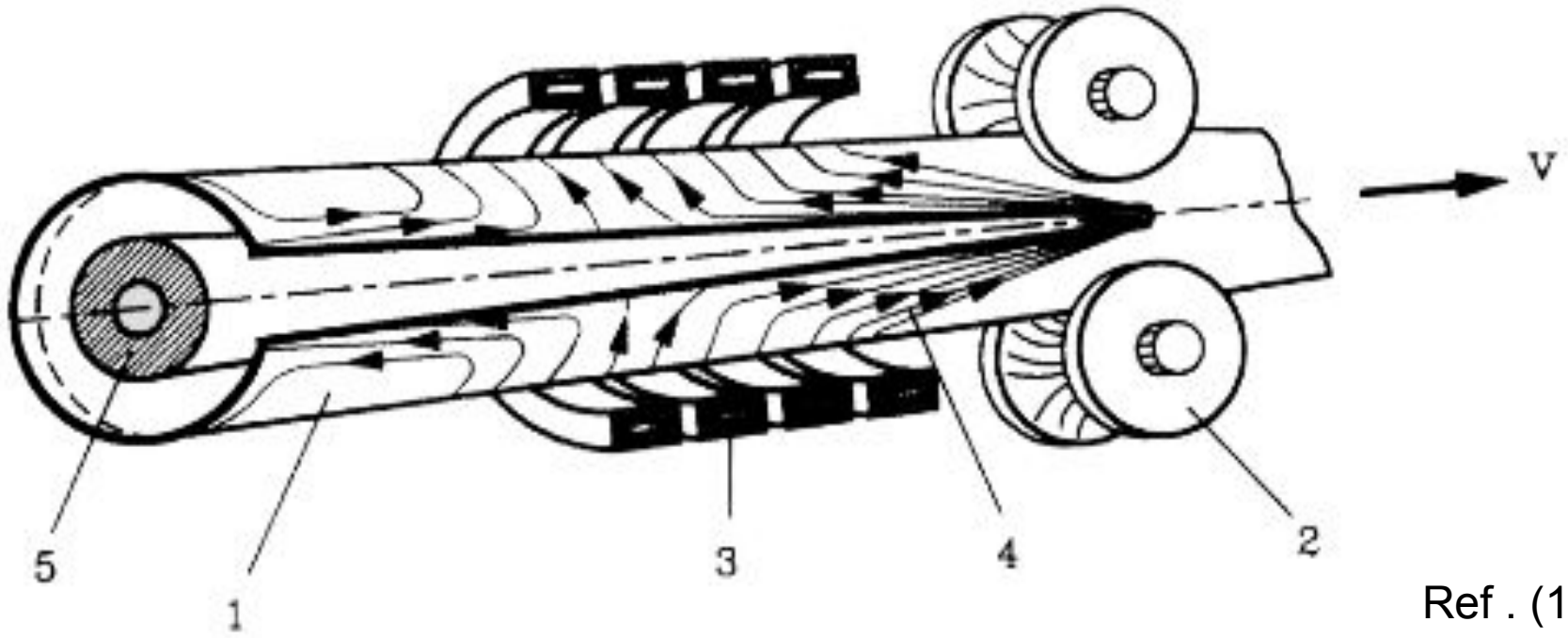
2022

Overview

- Induction Tube Welding Process
- The problem with welding small tubes
- Impeder core material optimization

What is induction tube welding?

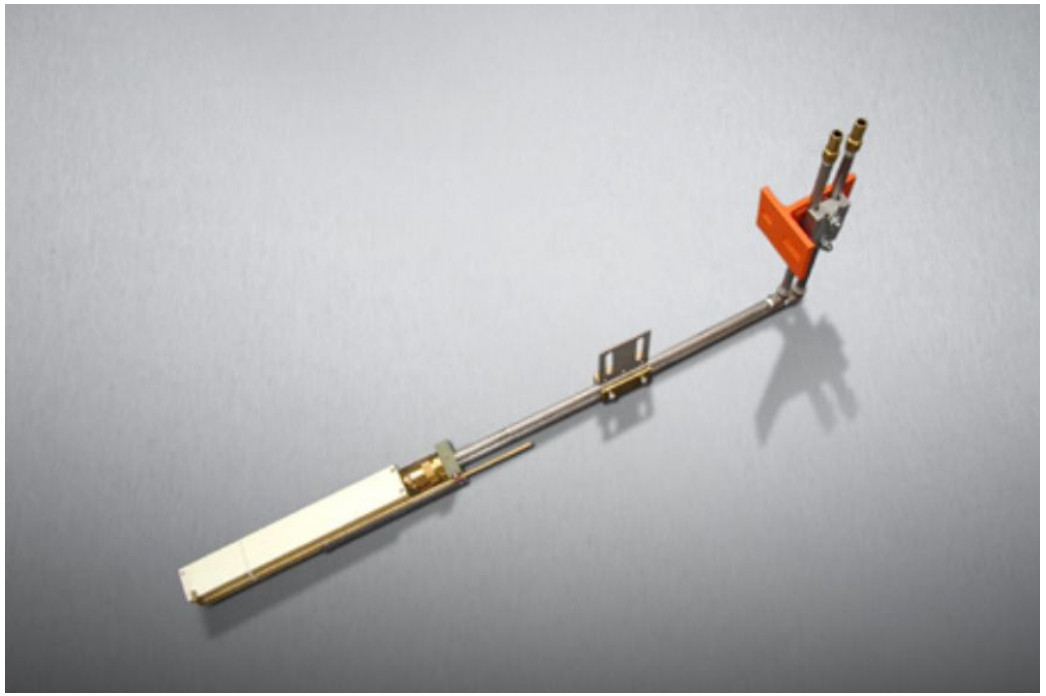
- A steel strip (1) is formed into a tube shape with a closing seam
- An induction coil (3) creates eddy currents in the tube
- An impeder (5) is used to force the currents along the weld vee (4)
- The heated tube edges are welded together via the weld rollers (2)



Ref . (1)

What is an impeder?

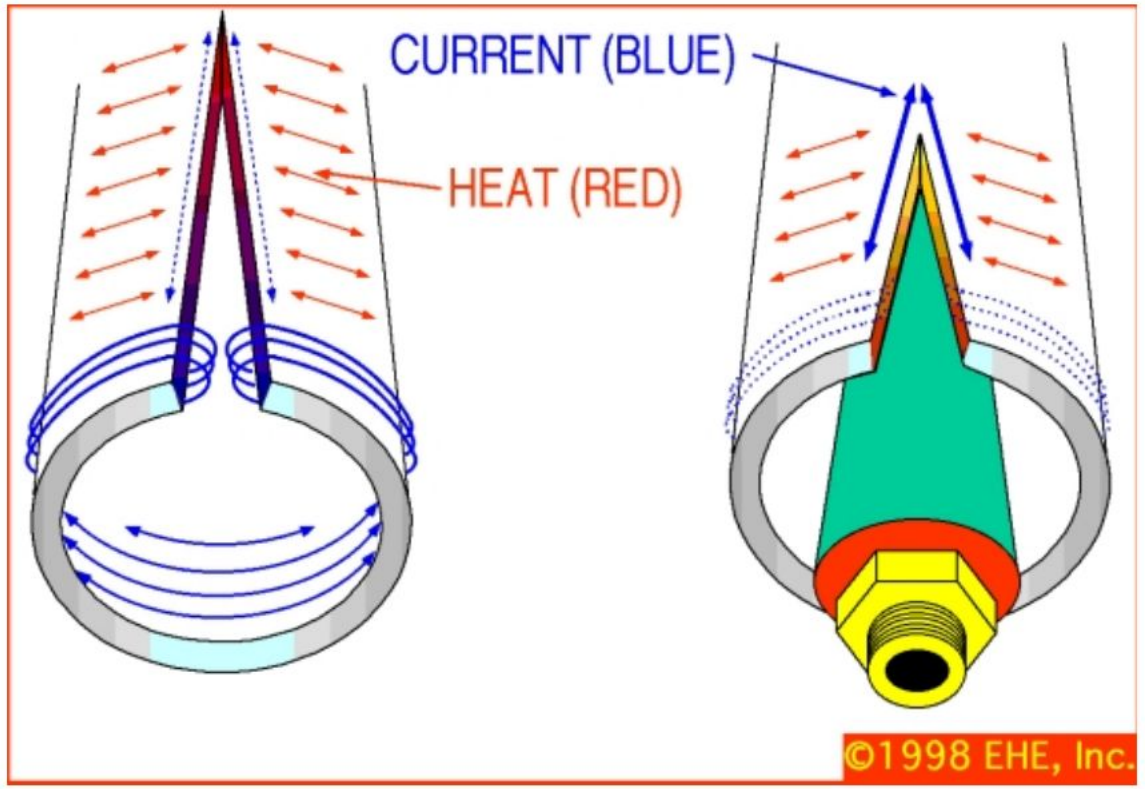
- A magnetic concentrator that directs current flow
- Typically manufactured using ferrite materials
- Fixtured within the forming tube



Ref . (2)

Induction tube welding magnetic circuit

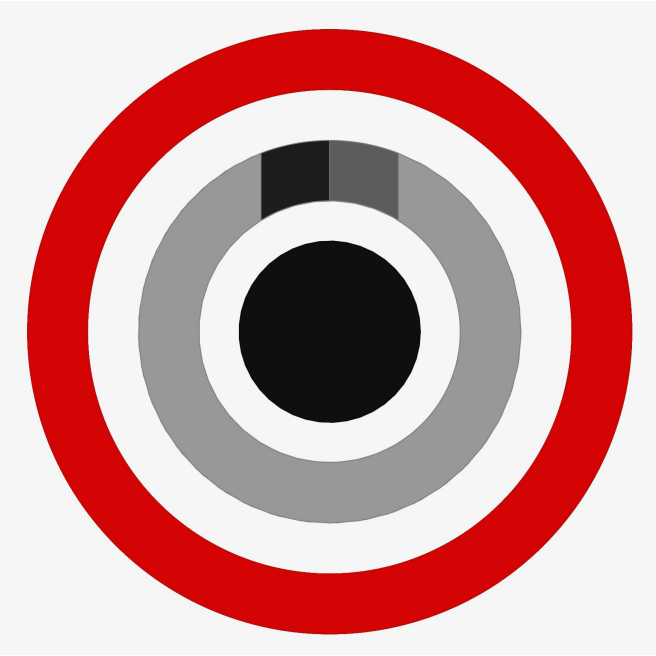
- Inductor drives current around the tube
- Two current pathways around the tube, weld vee and tube ID
- ID becomes more favorable with decreasing tube diameter
- Impeder raises impedance of ID path, forcing current to weld vee

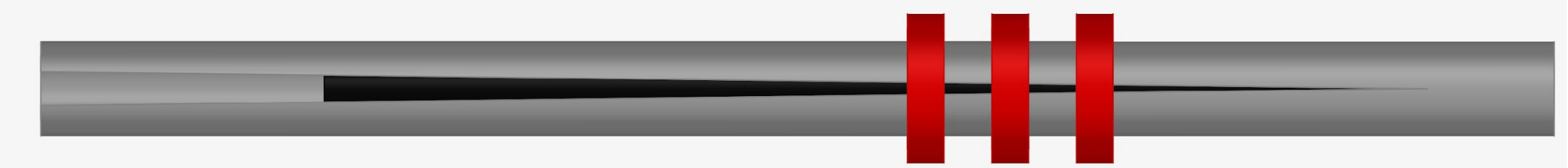


Ref . (3)

Small diameter thick-walled tube challenges

- Less space for the impeder core
- ID current path becoming more favorable
- These increase loading of the impeder
- Once the impeder reaches its saturation flux density, process efficiency plummets as current travels on the ID rather than along the weld vee





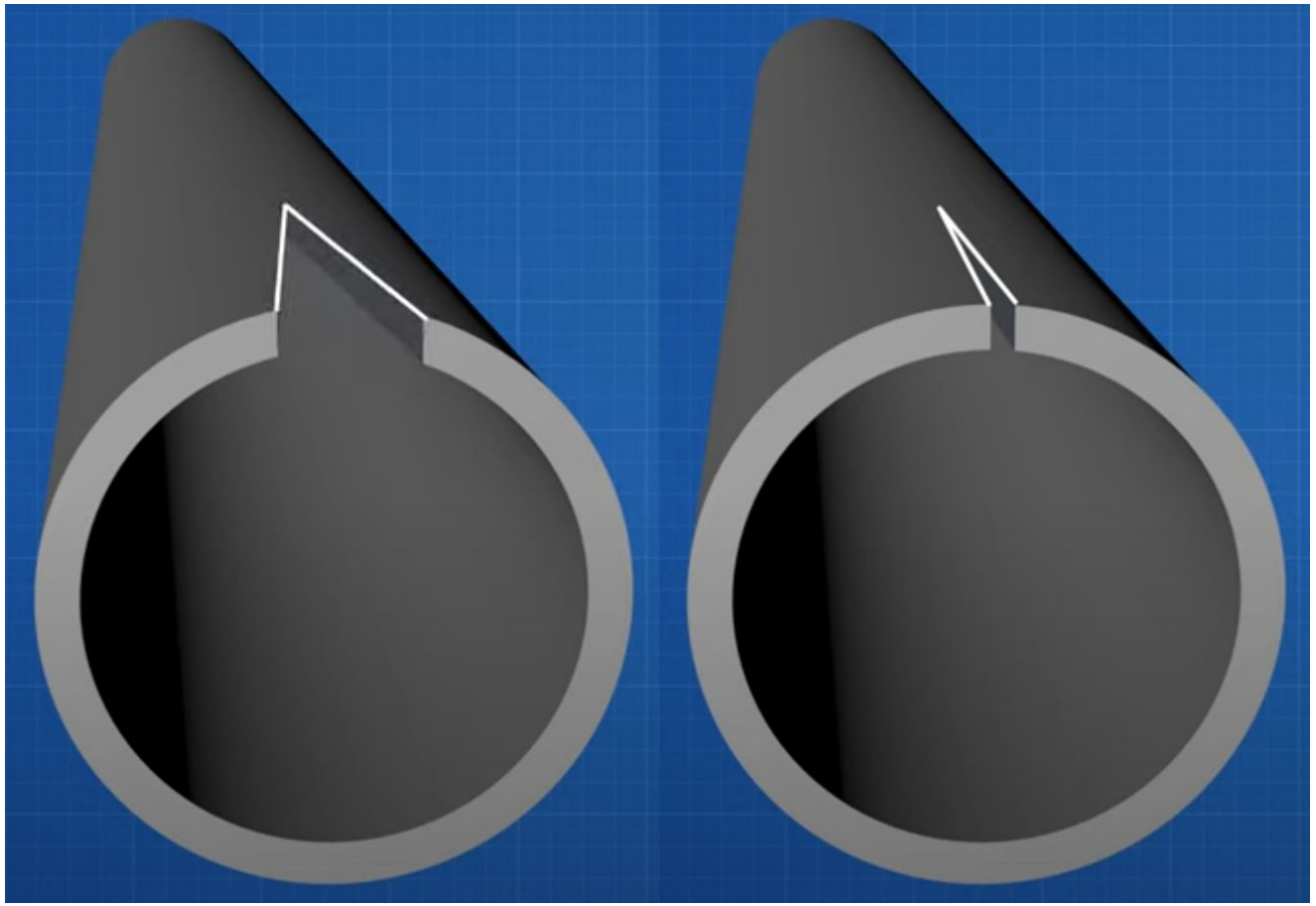
Solutions

- Add more power in cases where inefficiency is unavoidable
  - Wasted heating away from weld vee
  - Not feasible in many processes

- Increase process efficiency by:
  - Decreasing impeder loading
  - Increasing impeder load capacity

Decreasing impeder loading

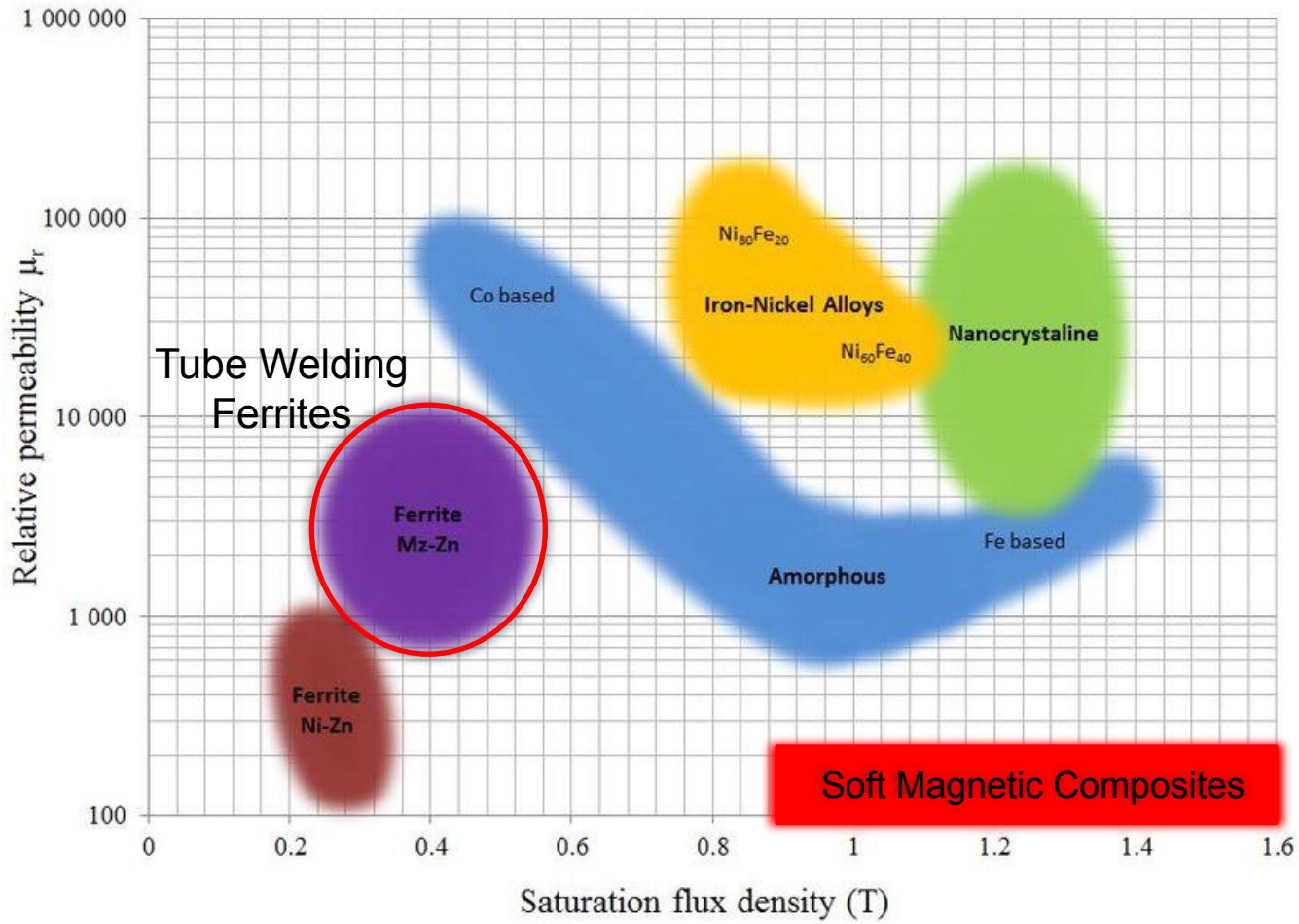
- Decreasing impeder loading by decreasing weld vee angle
  - Greater proximity effect
  - Lower impeder loading
  - Bigger issue in small tubes



Ref . (4)

Increasing impeder load capacity

- Increasing impeder load capacity
  - Use larger impeder
  - Greater cooling of the core
  - Use a material with a higher saturation flux density
    - Fettites are usually in the 0.4-0.5T range
    - Soft Magnetic Composites (SMCs) are usually in 0.9-1.6T range
- SMC permeability is lower, and losses are higher, however; improved saturation flux density is the key to performance



Ref . (5)

New technology adoption/transition

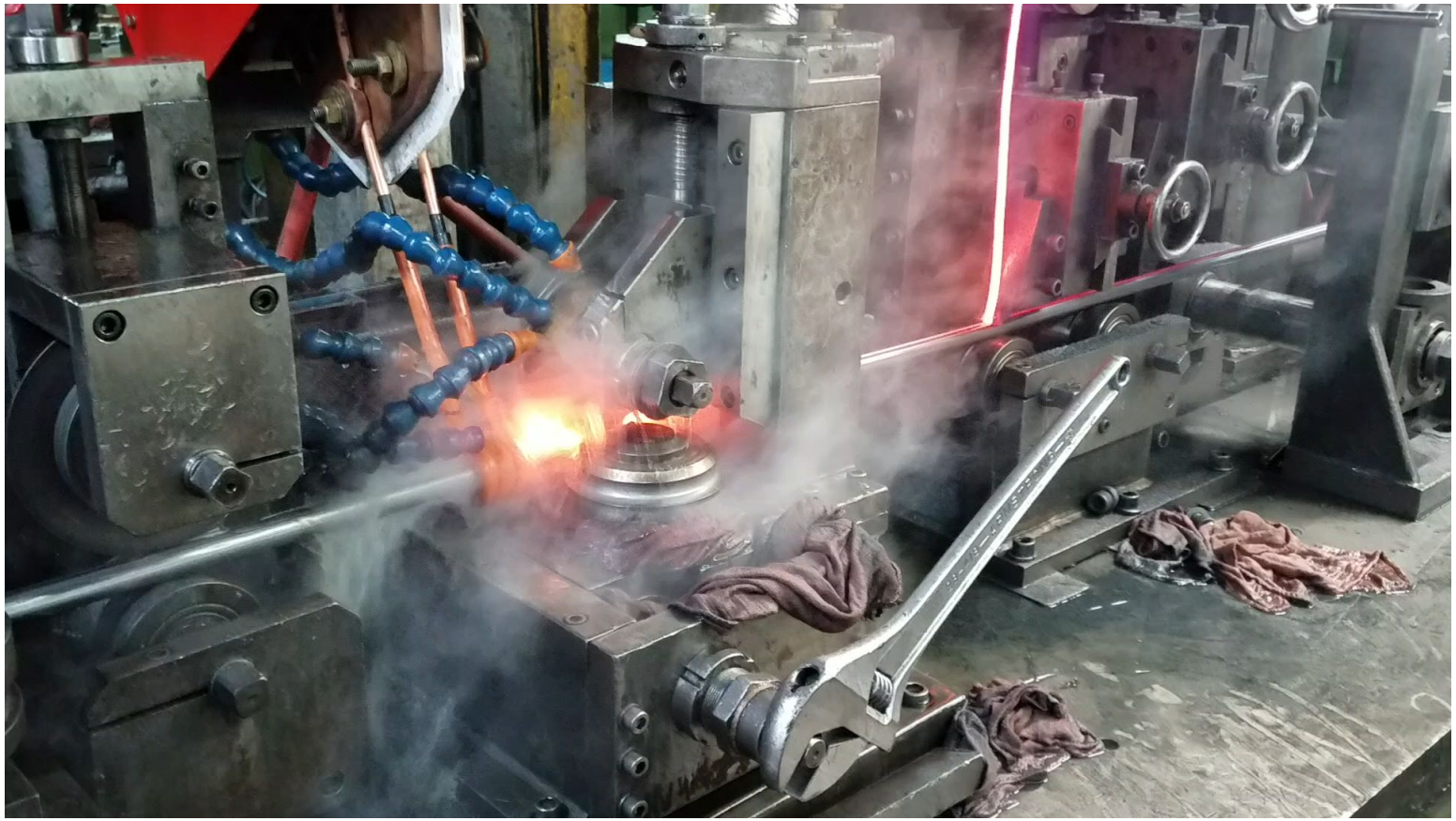
- Increase in process efficiency reduces overall power requirements
  - Process no longer in saturation, focuses power in weld vee
  - Enables increase in process uptime
  - Lower overall powers means less wear and tear
  - Higher saturation flux density drive smaller impeders with less mechanical impact failures
  - Induction coil and impeder changeovers drives downtime

Case study energy savings

- Case setups:
  - ~400kHz 100-300kW power supply
  - 19-20mm OD steel tube
  - 1-3mm thick wall
  - 9-10mm OD impeders
- Compared with the ferrite impeder, the SMC impeder reduced required power by 40-50% for the same line speed
- In cases where induction was limiting max line speeds, increased line speeds over 15% were observed

Case study SMC impeder lifetime

- The higher losses of SMC were of great concern in terms of thermal degradation
- Trials to test SMC impeder lifetime were run
- A few SMC impeders were lost immediately upon startup, as the power was turned on at nearly twice what was required to weld
- Some lost mechanically
- None lost to thermal degradation



Physical testing

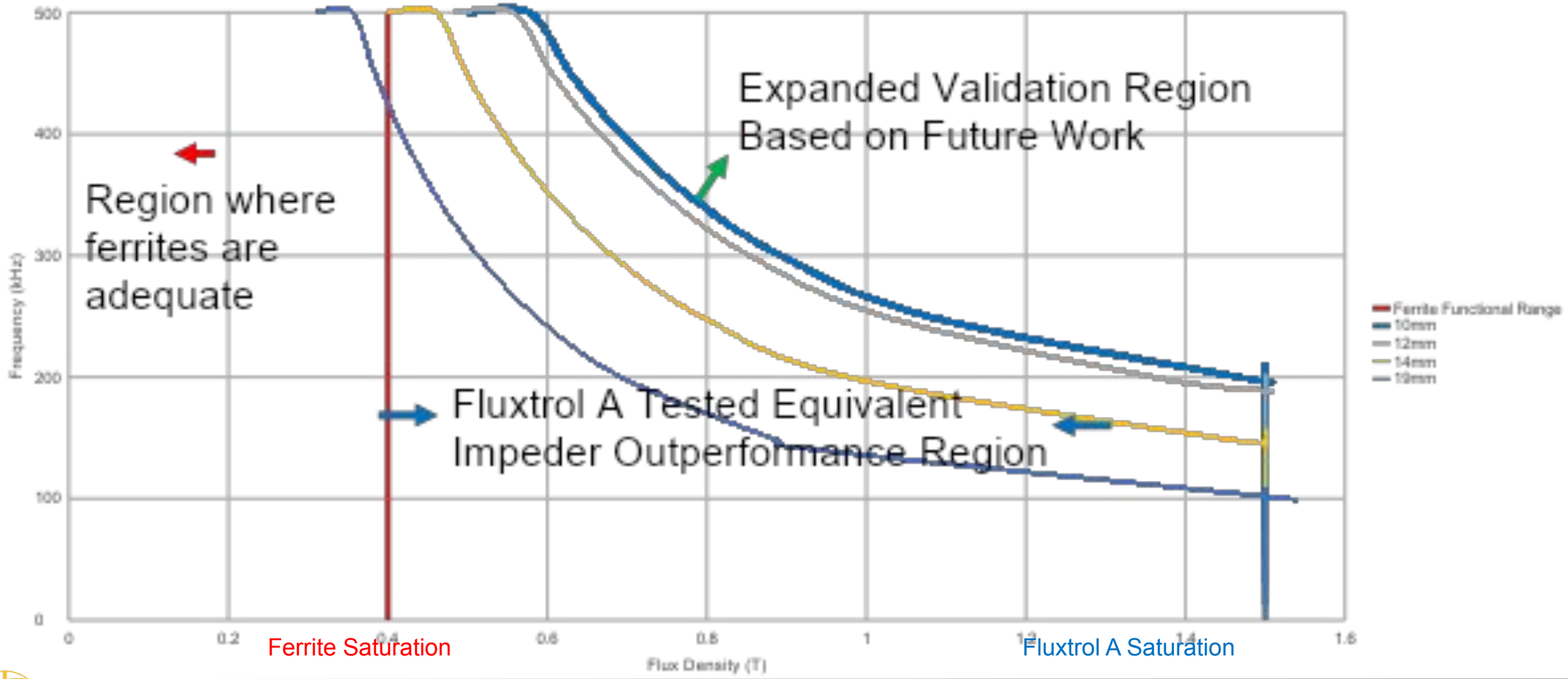
- This test stand was developed to determine if additional cooling is required for SMC impeders
- The stand can achieve magnetic loading in the impeder that mimics a real welding installation with impeder loading verified via simulation
- The water flowrate can be adjusted to pinpoint the cooling requirements at various levels of loading in the impeder

Physical testing result

- Shown here are the trials for a 12mm return flow impeder with a Fluxtrol A core
- The process was run at 330kHz and a maximum flux density of ~0.85T was achieved in the core
  - This is near double the typical maximum flux density of ferrites (0.4-0.5T)
- The cooling water supply was decreased until thermal degradation of the impeder was observed
- This test shows that SMC impeders can survive with typical cooling available to ferrite impeders (0.5GPM)
- We want to recreate this for even higher magnetic flux densities

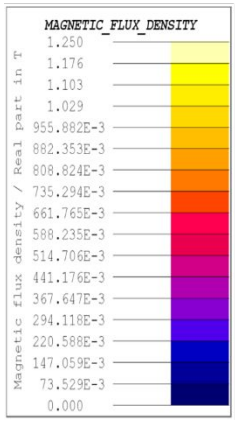
Trial	Max Flux Density (T)	Flowrate (GPM)
1	0.815	1.30
2	0.81	1.00
3	0.837	0.80
4	0.83	0.60
5	0.849	0.50
6	0.849	0.44
7	0.849	0.34
8	0.852	0.28

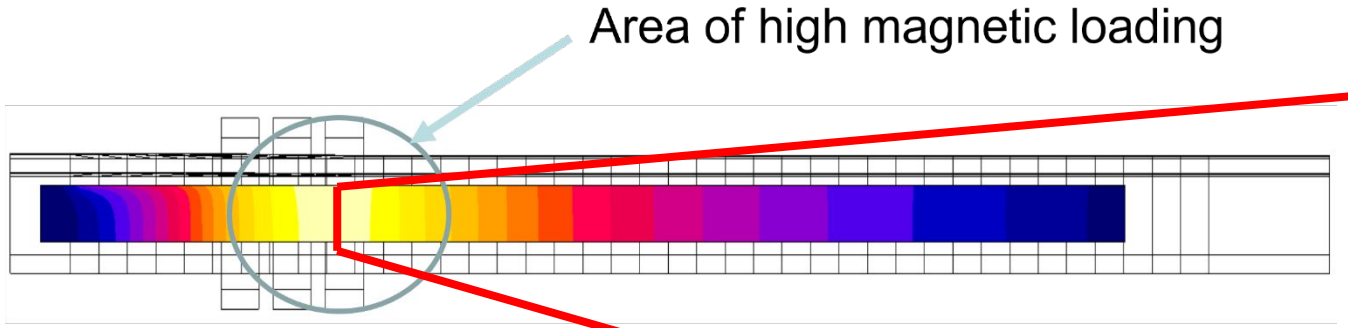
Operational Window

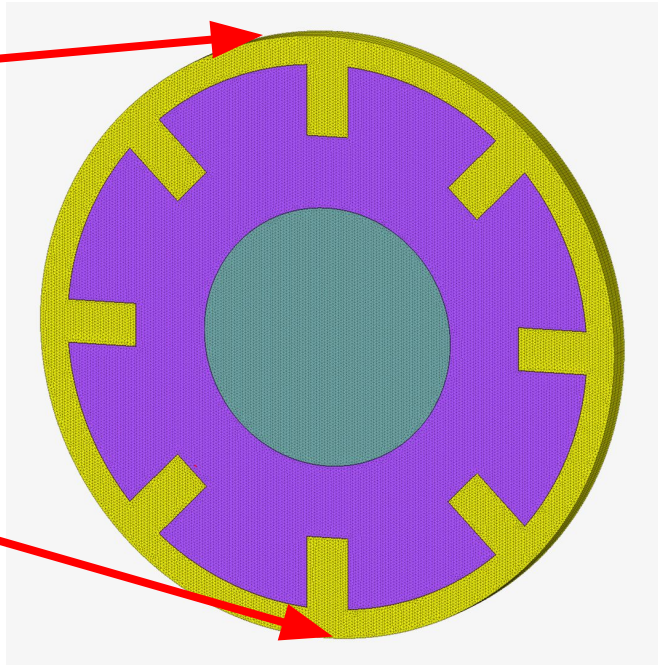


Computational modelling

- Focus on the most heavily loaded section of the impeder
  - Modeling at this location to validate survival at higher loading with 0.5GPM cooling



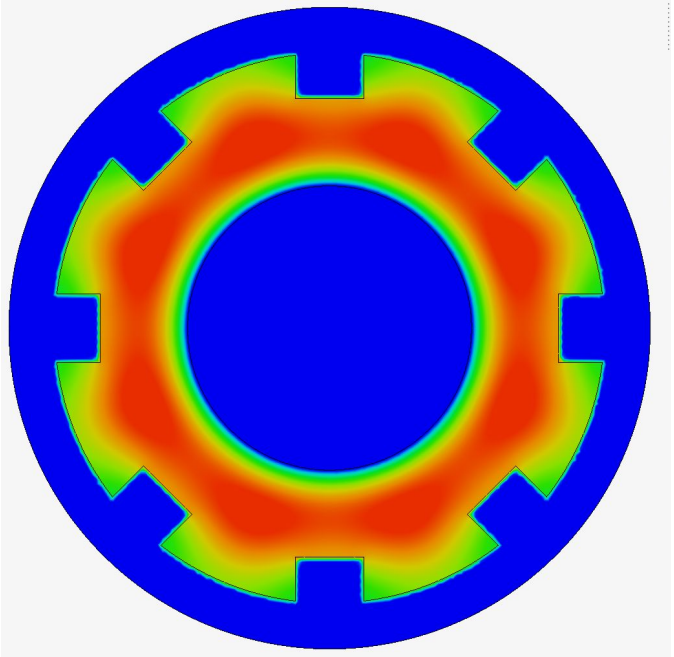




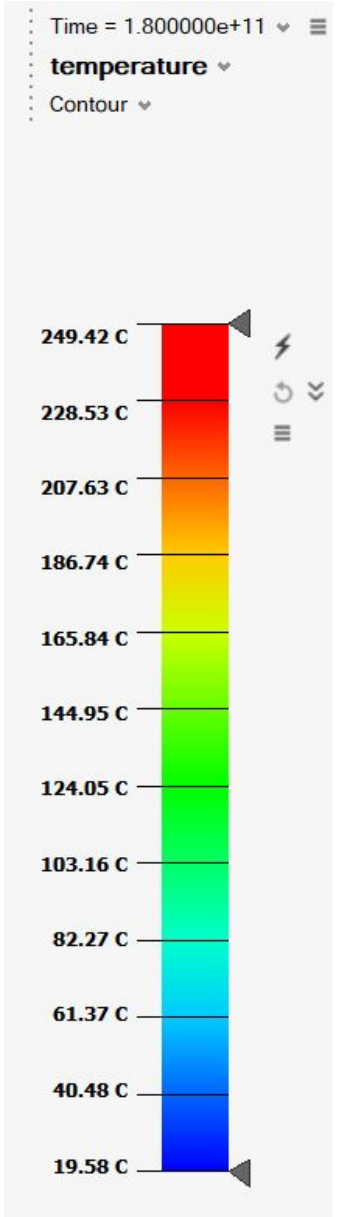
3D 1mm Extrusion of Impeder

Computational modelling results

- The trial where thermal degradation was initiated was modeled in CFD
- A temperature of 250°C achieved in the core is near the range for temperatures known to initiate degradation of Fluxtrol A
- This correlates with empirical data and can be used to validate the operational window for SMC impeders



Example Cooling of 12mm Impeder Failure Trial



Conclusions

- Small tubes have posed an issue in induction tube welding
- Only small improvements can be made when the impeder is saturated
- A change in impeder material provides much greater improvements in saturation flux density
  - Decreases required power
  - Increases weld performance and line speed
  - Decreases line downtime due to coil and impeder failures and replacement
- More testing needs to be preformed on induction tube mills for validation of SMC impeders

Future work

- A new physical simulation setup is being constructed to validated survivability of SMCs at higher flux density
- CFD modelling to be used to expand SMC impeder operational window
- Test impeders are going to be evaluated on production weld lines for better empirical performance data

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Q&A

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References

1) Image taken from UIE book “Induction Heating – Industrial Applications”
2) https://www.efd-induction.com/en/induction-heating-equipment/weldac-tube-welder
3) Image taken from Tube & Pipe Technology “Optimizing Efficiency in HF Tube Welding Processes”
4) Images taken from Thermatool Corp’s YouTube “Proximity Effect for High Frequency Welding of Tube and Pipe − Thermatool”
5) https://www.researchgate.net/figure/Relative-permeability-vs-saturation-flux-density_fig1_321357089

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