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Characterization of Soft Magnetic Composite Impeders

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INTERNATIONAL MATERIALS,
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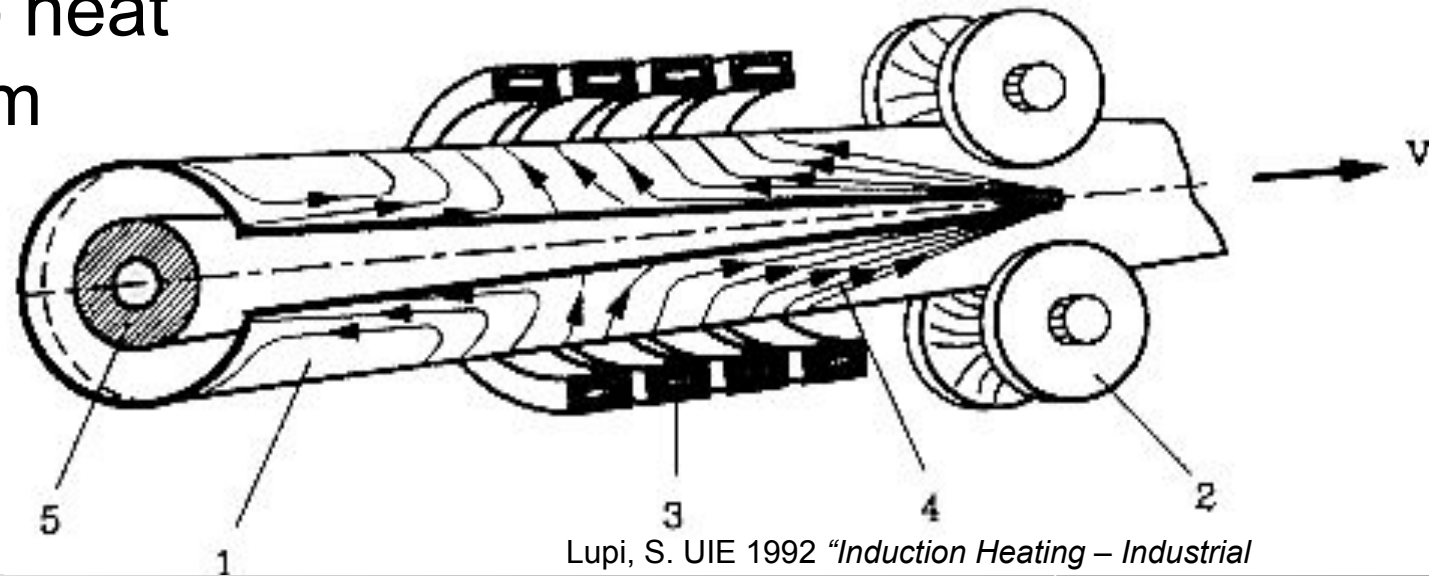
2024

Overview

- The Induction Tube Welding Process
- Impeder Benefits and Material Selection
- Tube Welding Case Studies
- Soft Magnetic Composite Impeder Characterization
- Carbon Reduction and Future Work

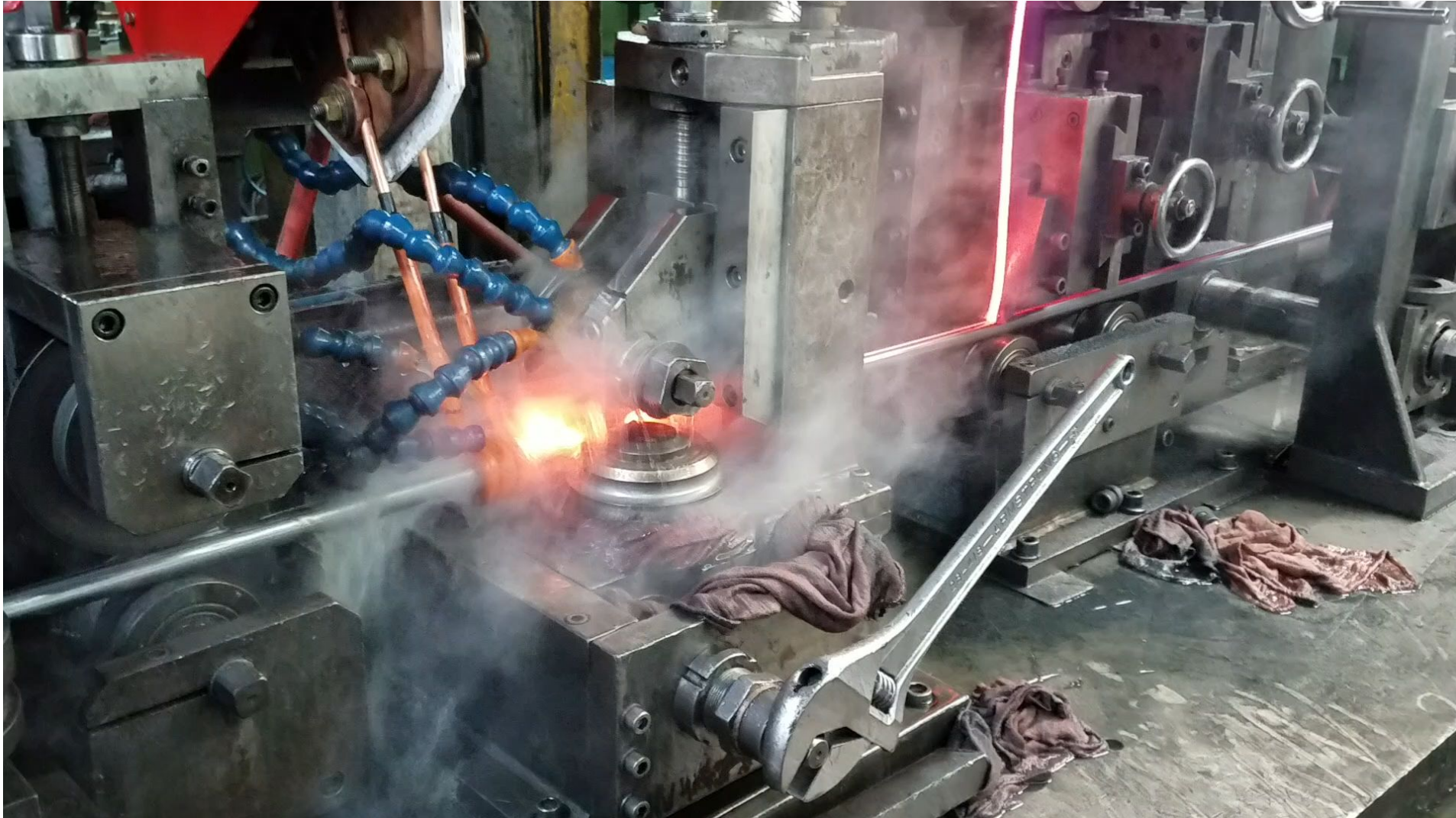
The Induction Tube Welding Process

- Inductive welding is used for making tubes for a variety of industries
- The Induction Tube Welding Process involves:
 - A steel strip run through forming mills to create the tube shape with a closing seam
 - An inductor which is used to heat the inside edges of this seam
 - The softened tube edges being squeezed together to form a weld



Lupi, S. UIE 1992 "Induction Heating – Industrial Applications"

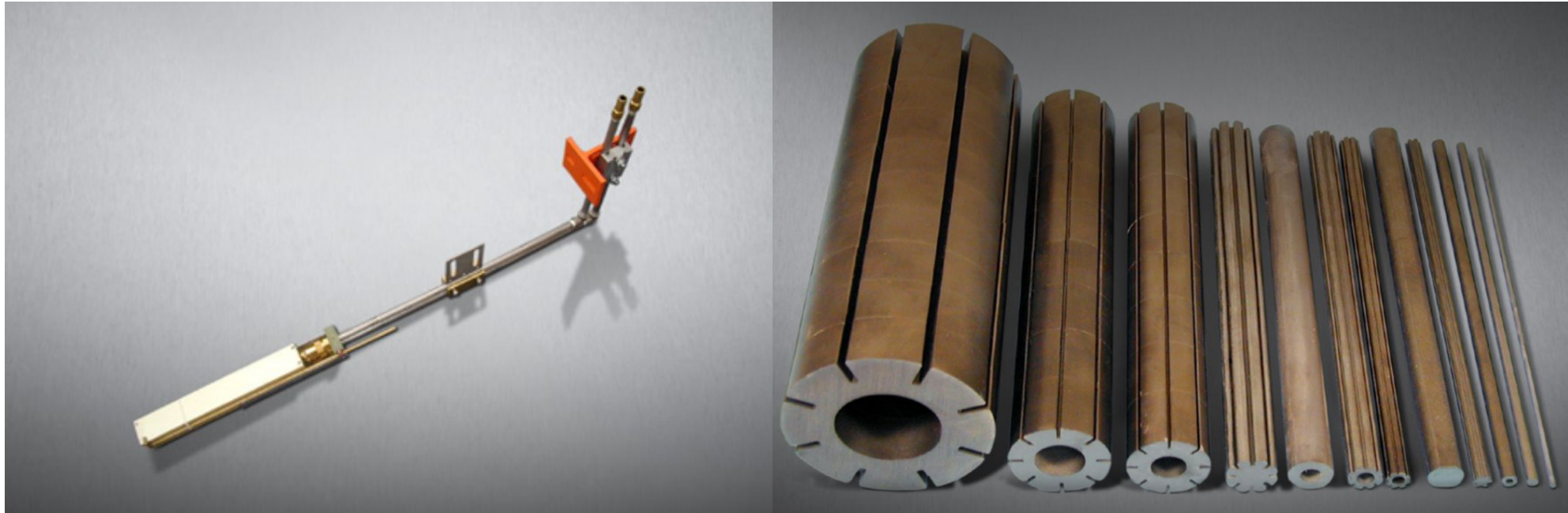
The Induction Tube Welding Process



<https://fluxtrol.com/ASM-HTS-2019-improving-inductive-welding-system-performance-with-soft-magnetic-composites>

What is an Impeder?

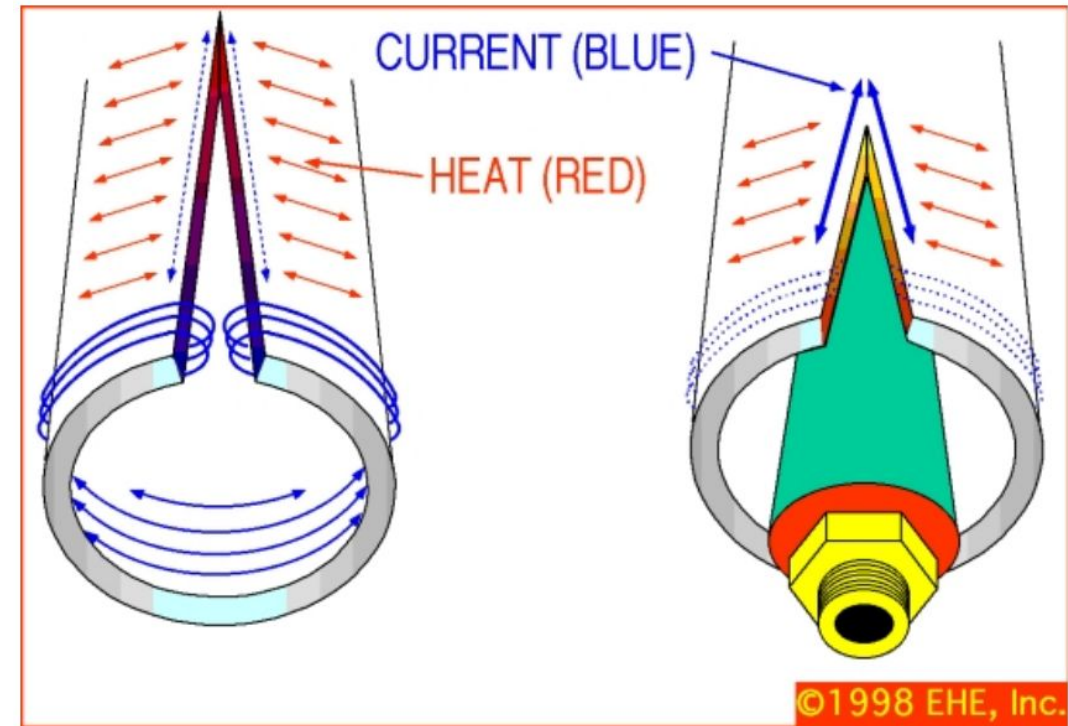
- A magnetic concentrator fixtured within the forming tube that directs current flow
- Without this component these systems would run very inefficiently, and in some cases, they could not run at all
- In production, if the impeder is damaged via thermal degradation or mechanical loss, the line is stopped and the impeder replaced before production can resume



EHE US Product Catalog 2018

How Does an Impeder Work?

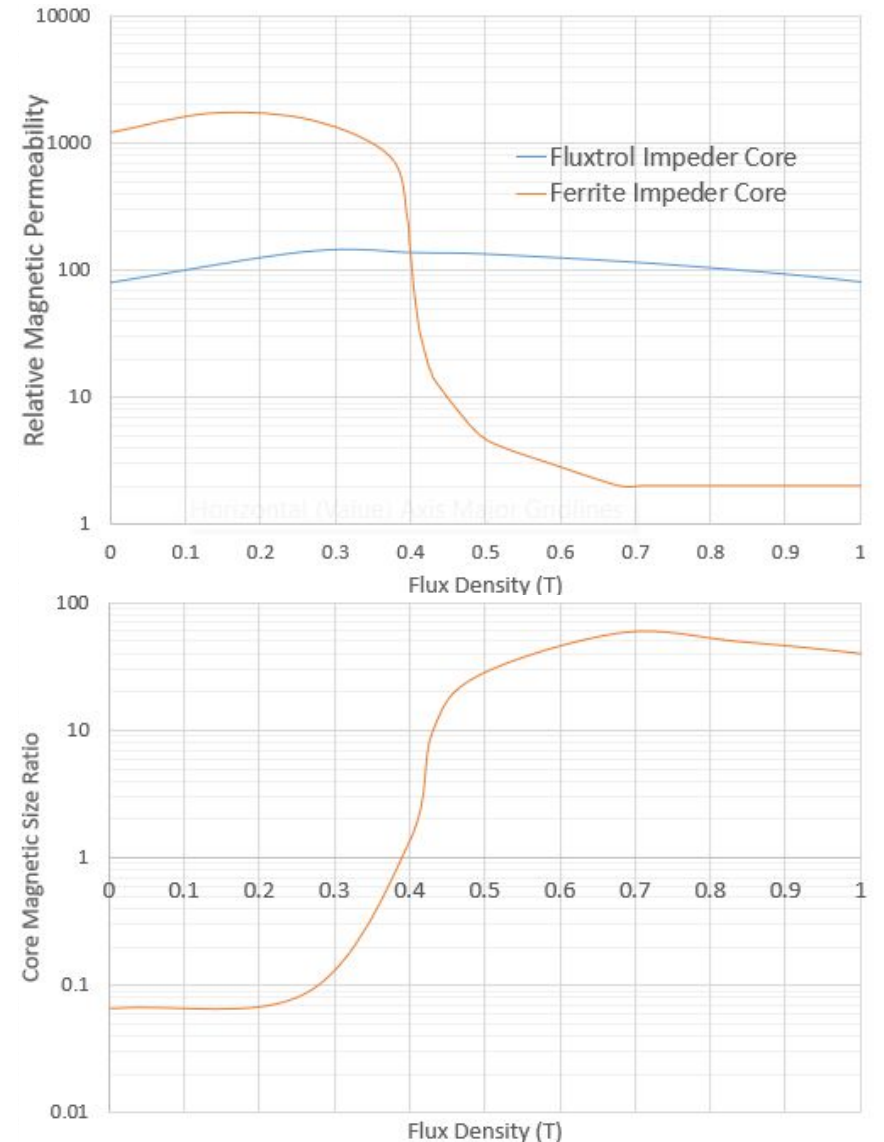
- The alternating magnetic field generated by the induction coil creates two major competing current pathways around the tube:
 1. Along the weld vee
 2. Around tube ID
- The impeder raises impedance of ID path, forcing current to weld vee
- The maximum efficiency possible in the system is determined by the impeder's ability to carry magnetic load
- If the impeder's permeability drops due to saturation, it can no longer carry the magnetic load and energy is wasted on the ID path



Wright, John. Tube & Pipe Technology *"Optimizing Efficiency in HF Tube Welding Processes"*

Fluxtrol A vs Ferrite Core Comparisons

- A ferrite's relative magnetic permeability is much higher than that of Fluxtrol A at low flux densities
- As the saturation flux density for a typical ferrite is $\sim 0.4\text{T}$ there it is possible for ferrites to run with slightly greater efficiency in this region due to their higher permeability
- At higher flux densities, between $0.5 - 1\text{T}$, Fluxtrol A cores maintain their permeability as its saturation flux density is 1.2T , while ferrite permeabilities drop
- Once the ferrite core is saturated, Fluxtrol cores can carry 20 – 50 times their load as they maintain their relative magnetic permeability
- When permeability is high the system is in the regime of high process efficiency



Getting the Most Out of an Impeder

- If the impeder can carry the magnetic load of the ID path, the system is running near the maximum theoretical efficiency
- To carry additional magnetic load, either the cross-sectional area of the impeder or the saturation flux density of its material needs to be increased
- In small tubes, space is limited, but a change in material can increase the saturation flux density and total capacity
- With good cooling, SMC's can carry over double the 0.4T saturation flux density of typical ferrites under typical tube welding conditions, meaning the power in the region of high process efficiency can be increased substantially

$$\begin{aligned} & \text{Regime of High Process Efficiency} \propto B_{\text{impeder}}^2 \\ & \left(\frac{B_{\text{SMC}}}{B_{\text{Ferrite}}} \right)^2 = \left(\frac{0.8}{0.4} \right)^2 = 4 \times \text{Regime of High Process Efficiency} \end{aligned}$$

Material Selection

Soft Magnetic Composite (SMC)

- Higher Saturation Flux Density
 - Higher potential line speed
 - Energy savings
 - Increased mechanical tolerances
 - Potential to improve tube quality
- Temperature/time stability of magnetic properties
 - Improved stability of production (ferrite properties very sensitive to temperature and stresses)
- Case studies have been carried out to make a comparison between these materials in the field

Ferrite

- Lower cost
- Lower Losses
 - Require less cooling to avoid failure
- Can run in saturation without failure, just reduced process efficiency

FAHOP Company Case Study

- Case setup:
 - ~400-500kHz 250kW power supply
 - 21-27mm OD steel tube
 - 2.6mm thick wall
 - 13mm OD impeders
- Power required for each impeder material was recorded at various line speed between 10-60 m/min
- Energy savings for the same line speeds were between 30-50% when using Fluxtrol A

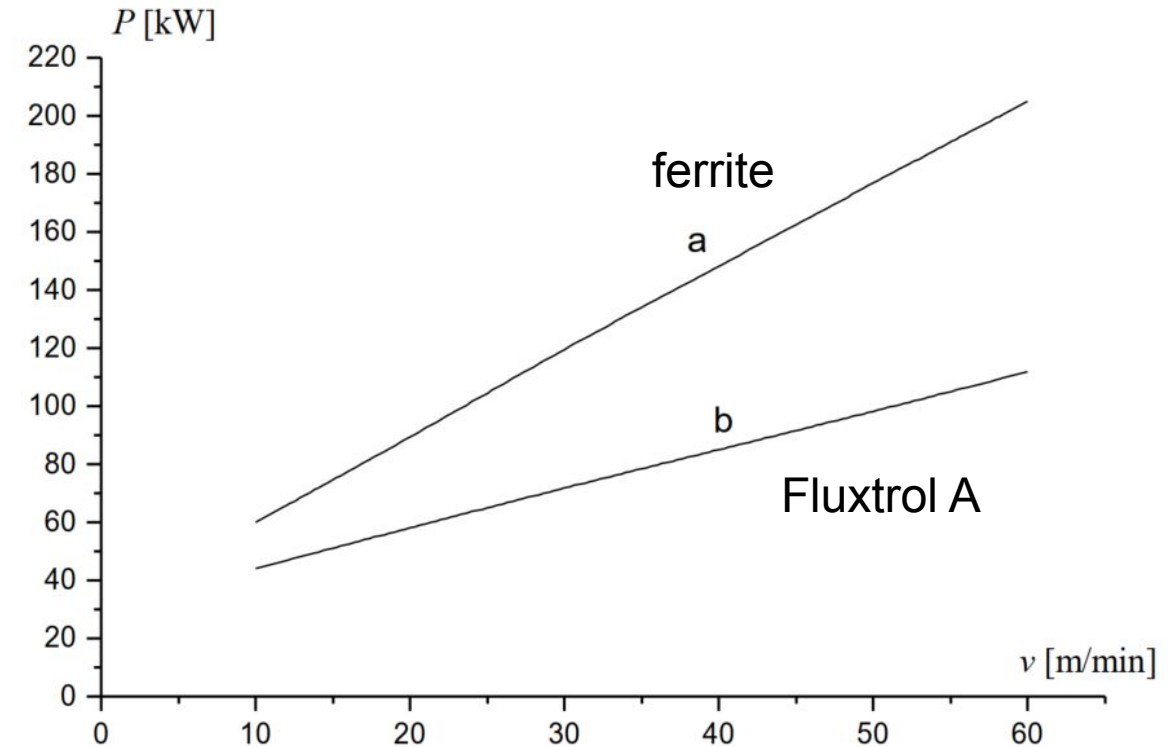


Fig. 3 – Rectifier power as a function of production speed.

Milicevic, Miroslav & Nejkovic, Valentina. 2024 Proceedings of the Romanian Academy, Series A. Vol 25. pp 55-64. *Implementation of Optimal HF Welding Procedure of Steel Pipes for High-Quality and Energy-Efficient Welds.*

FAHOP Energy Savings

- This study shows that there is an opportunity to save 20-100kWh when switching the impeder from a ferrite to Fluxtrol A
- At the highest line speed, this prevents 350 tons of CO² emissions per year and saves \$40,000 in electricity costs using the following assumptions:
 - ¹A CO² emissions factor of 6.99*10⁻⁴ tons/kWh
 - 2 shifts, 7 days or ~5000 hr/year of production
 - ²\$0.08 per kWh

| | Line Speed (m/min) | Power (kW) |
|-----------------|--------------------|------------|
| 13mm Ferrite | 10 | 60 |
| 13mm Fluxtrol A | 10 | 40 |
| 13mm Ferrite | 60 | 210 |
| 13mm Fluxtrol A | 60 | 110 |

1) EPA (2022) AVERT, U.S. national weighted average CO2 marginal emission rate, year 2021 data. U.S. Environmental Protection Agency, Washington, DC
 2) https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_03

2019 Case Study

- Case setup:
 - ~400kHz 100-300kW power supply
 - 19-20mm OD steel tube
 - 1-3mm thick wall
 - 10mm OD impellers
- Energy savings for the same line speed were between 15-50%
- Without a power limitation, line speeds were increased by over 15% with the flying saw being the bottleneck
- Tube quality was maintained even at the higher production speeds



2019 Case Study Energy Savings

- This study shows that even at increased line speeds there is an opportunity to save over 100kW of power
- Using the same assumptions as the previous case:
 - Running at the same line speed prevents 437 tons of CO2 and saves \$50,000 in electricity costs
 - Running at the higher line speed prevents 479 tons of CO2 and saves \$55,000 considering the same amount of product would be manufactured in 730 fewer hours

| | Line Speed (m/min) | Power (kW) |
|------------------|--------------------|------------|
| 10mm Ferrite | 82 | 325 |
| 10mm Fluxtrol 75 | 82 | 200 |
| 10mm Fluxtrol 75 | 96 | 220 |

Prinz & Co. GmbH Stahlrohre Case Study

- Case setup:
 - ~400kHz 50-150kW power supply
 - 15mm OD steel tube
 - 1.2mm thick wall
 - 8.5-9mm OD impeders

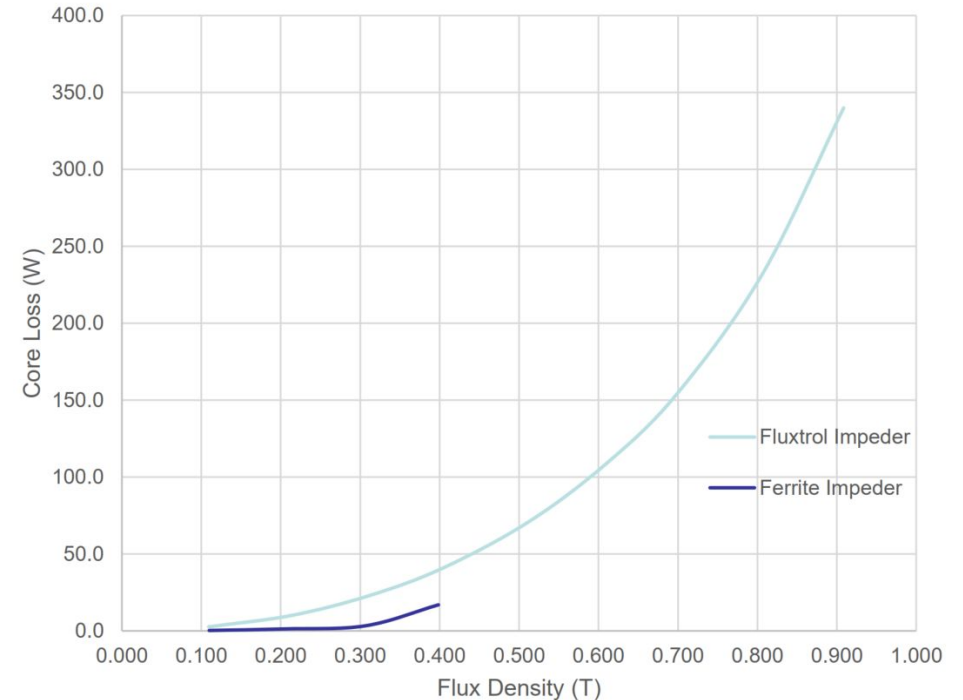
| | Line Speed (m/min) | Power (kW) |
|-------------------|--------------------|------------|
| 9mm Ferrite | 77 | 58 |
| 8.5mm Fluxtrol 50 | 77 | 33 |

- Energy savings for the same line speed was ~40%
- >20 hours impeder life with little to no sign of wear
- This smaller tube has less space for an impeder which makes it more prone to saturation
- Even though the tube size and wall thickness is smaller than the previous two studies, energy savings is 25kW or the equivalent of preventing 87 tons of CO² per year and saving \$10,000

Gunther, D., Kroll, M., Goldstein, R., Kunke, A., UIE 2024. *Geometry Optimization and Efficiency Increase of HFI Welding Process While Using SMC-impeders*

Challenges in Implementation

- In these small tube lines, there is an opportunity to save 87-479 tons of CO² emissions per year by increasing process efficiency
- If there are such obvious benefits for making the change, then why are we not seeing SMC impederes in all production lines of this type?
- SMC's greater saturation flux density come with greater losses
- Induction tube mills are not used to an impeder that can fail in this fashion and so low water or using power supply setpoints twice as high as required can lead to catastrophic failures



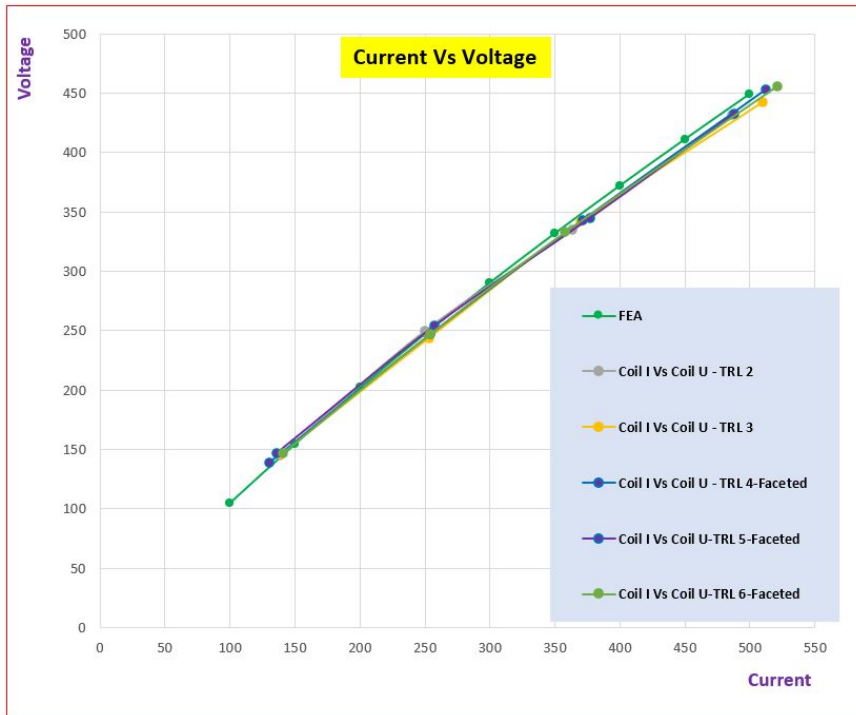
Test Stand

- A physical test stand was created to verify the loading of SMC impederes and that they could survive the electromagnetic conditions of a tube welding system under these loads:
 - 25kW 135-400kHz induction power supply
 - 3-Turn induction coil
 - Impeder positioned within the coil
 - Chiller to supply the impeder cooling water to control the flowrate and temperature
 - Various measurement devices to measure coil current and voltage as well as the ΔT in impeder cooling water



Test Data 10mm Impeder: @ 200 KHz

Maximum Flux Density Tested ≈ 1.2 T

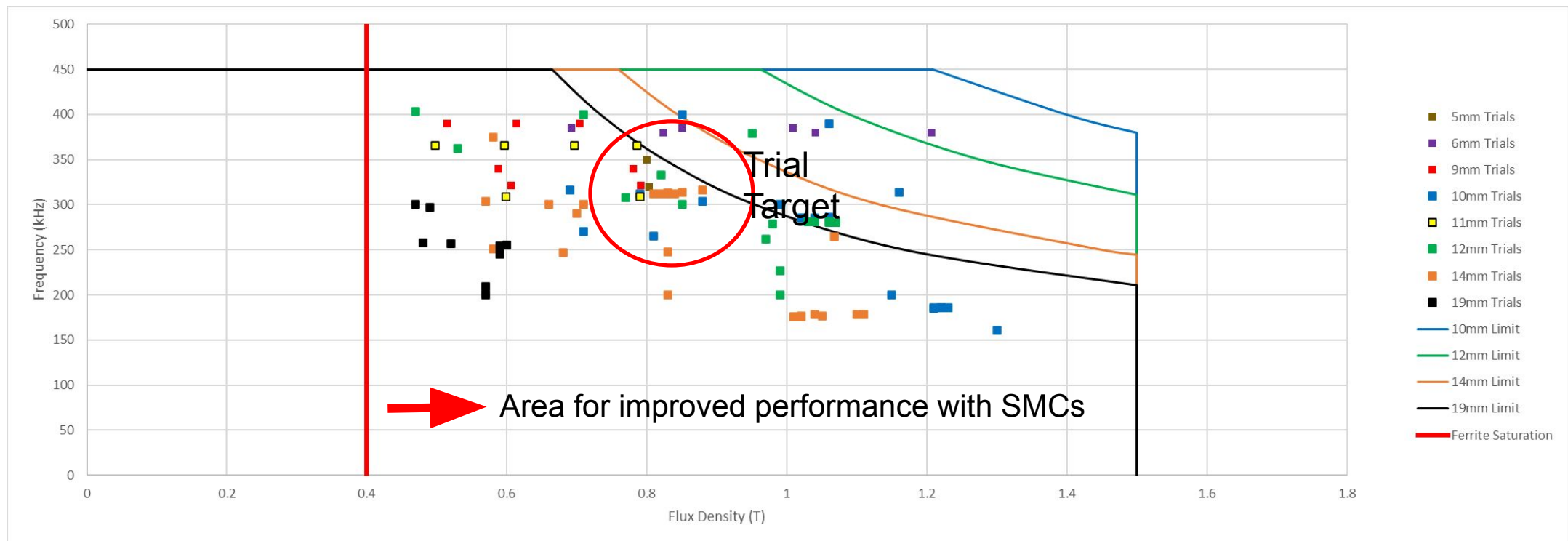


- Tested 5 Impeders at the same power setpoints
- Experimental data are well correlated with simulation results
- Power loss deviation is less than 5%.

| Power Loss Deviation % at Max PS | | | |
|----------------------------------|-------|------|--------|
| | TRL # | FEA | Dev. % |
| Trl # 2 | 3.43 | 3.4 | 1.5% |
| Trl # 3 | 3.51 | 3.5 | 0.3% |
| Trl # 4 | 3.63 | 3.51 | 3.4% |
| Trl # 5 | 3.41 | 3.42 | 0.3% |
| Trl # 6 | 3.6 | 3.54 | 1.7% |

Fluxtrol Impeder Operational Window

- Below are the results of some of the trials run on the test stand, as well as the theoretical limits for various impeder sizes based on simulation
- More recent trials target $0.85T@300kHz$ and last for 4 hours to confirm durability
- This provides the opportunity for up to 4 times greater power for the regime of high efficiency, and is in the middle of the frequency range for these types of mills



Conclusions

- Case studies have shown many benefits when replacing ferrite impellers in saturation with ones made of soft magnetic composites:
 - 20-50% energy savings at same production level
 - Ability to increase production speeds
 - Increased process stability/reduced downtime
 - Equal or better product quality
- Given the demonstrated savings of 87-479 tons of CO² per line per year, there is a significant opportunity to reduce global emissions without reducing productivity – with the potential for more
- If we assume 500 small tube welding lines globally and 300 tons of CO₂ reduction per line reduction, there is an opportunity for total Carbon Reduction of 150 kTons CO₂ reduction Globally Annually
 - Increase in grid capacity of 40 MW, which could be applied to other electrification applications to further Decarbonization Efforts

Future Work

- To help better understand the limits of SMCs for use in induction tube welding system further trial on the Test stand and simulations are being done to determine the operational limits of SMC impeder cores
- Work is being done to demonstrate the capabilities of SMCs for use in tube mills that require internal scarfing
 - The inclusion of a metal arm passing through the impeder core creates an even greater need to avoid saturation of the core
- Acceptance of SMCs for use as a replacement impeder material is growing and further field testing is planned for 2024



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Q&A

Acknowledgments: Sahadev Khatri, Joseph Luellen, David Morris



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