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Physical Simulation and Computational Modelling for Validation of Soft Magnetic Composite Impeder Performance

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HES-23

Background

- 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
- In systems with small tube diameters and thick walls, magnetic saturation of the impeder can become a limiting factor which creates an opportunity to improve the welding system performance using soft magnetic composite materials (SMCs)

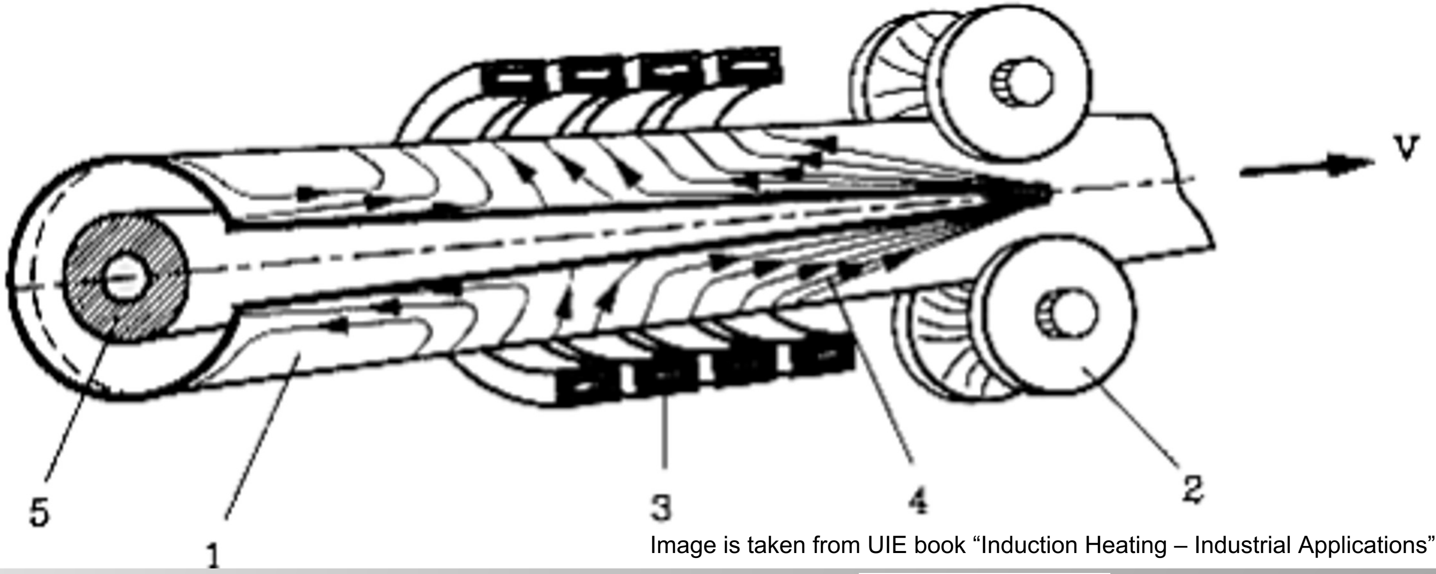
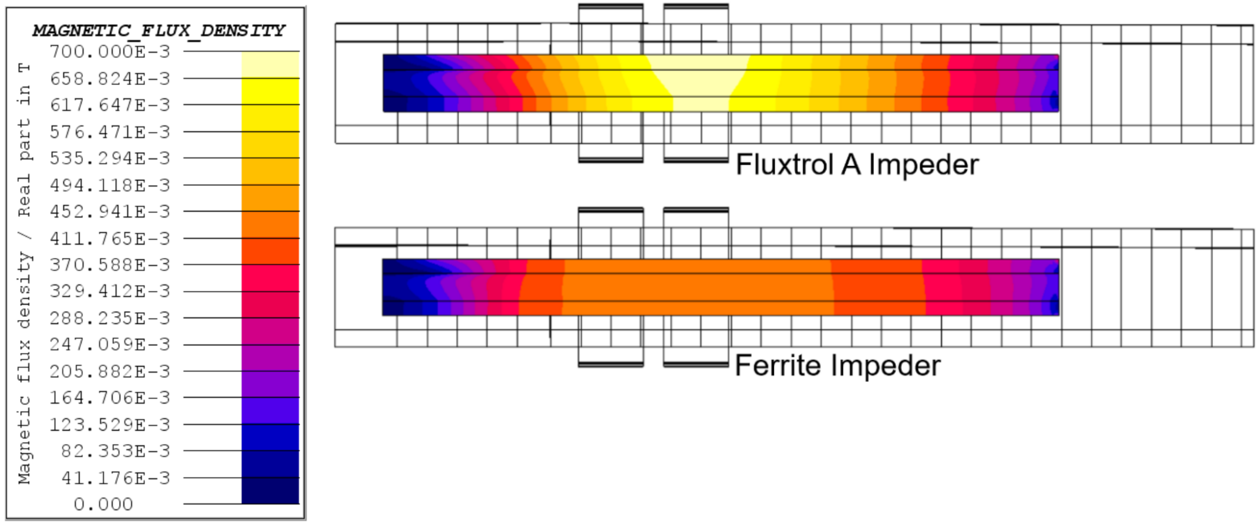
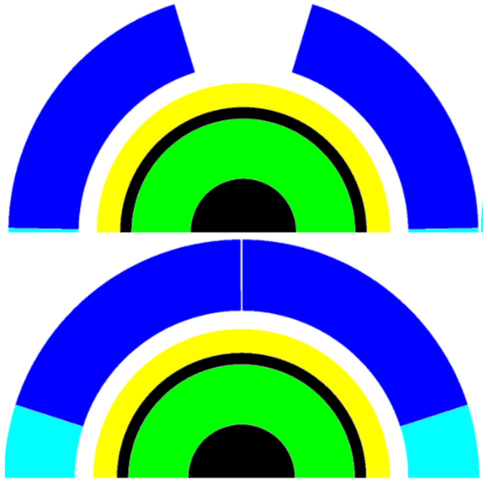


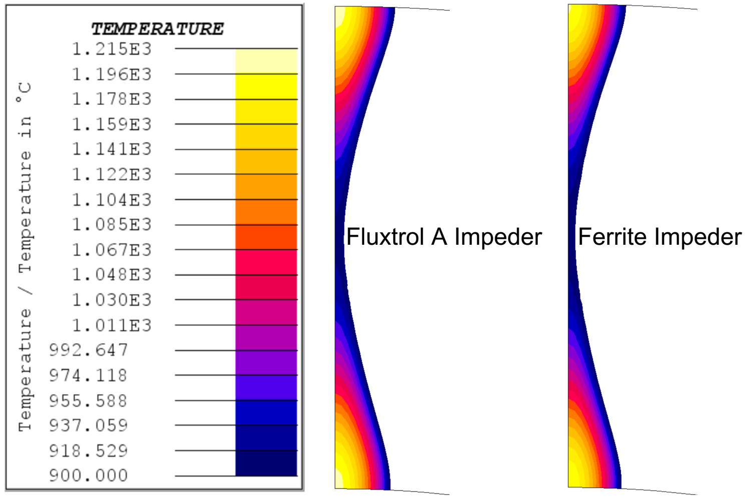
Image is taken from UIE book "Induction Heating – Industrial Applications"

HES 2019 Simulation Impeder Comparison

- The electromagnetics of a tube welding system was modeled in 3D and the current calculated in the tube was taken and used to simulate the thermals in the weld vee to compare an impeder made of Ferrite to one made of Fluxtrol A
- Welding temperatures were achieved at the weld vee; however, the Fluxtrol A impeder required 25% less current in the inductor and 11% less power

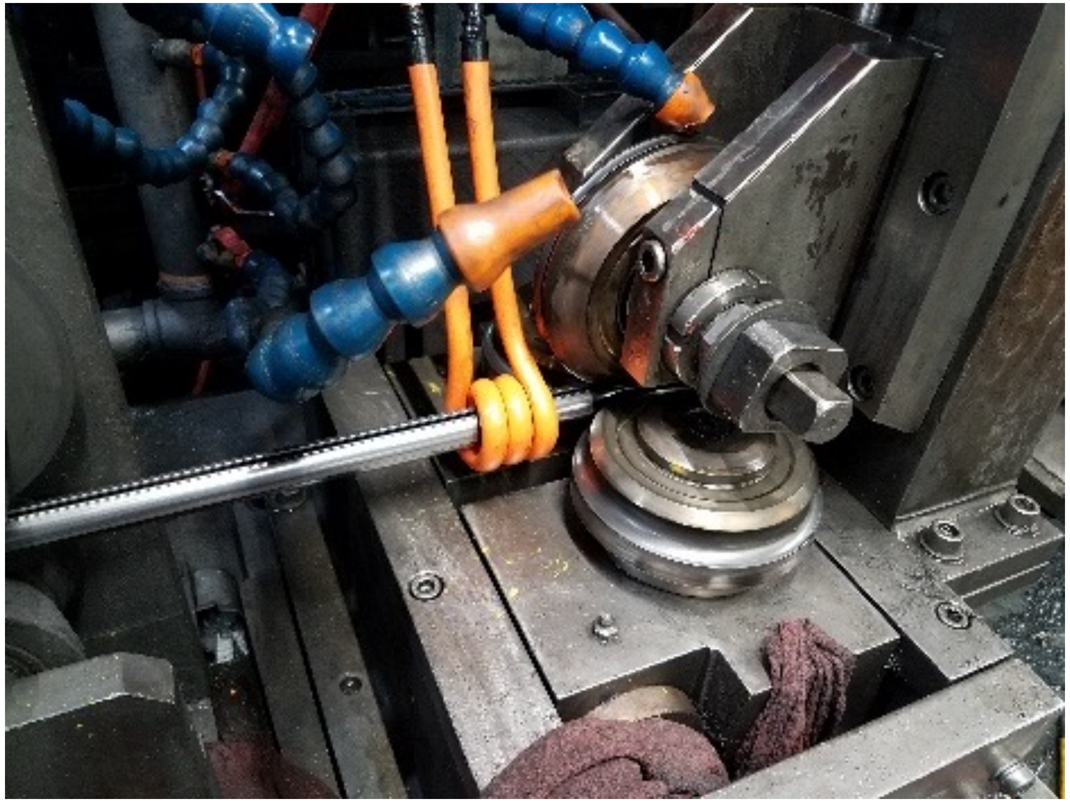






Impeder Comparison Case Studies

- Case setups :
  - ~400kHz 100-300kW power supply
  - 19-20mm OD steel tube
  - 1-3mm thick wall
  - 9-10mm OD impeders
- Energy savings for the same line speed were between 15-50%
- For cases where the ferrites were saturated and switching to an SMC provided a resource in power, line speeds were increased by over 15%
- These results lined up well with simulated results for these sized systems

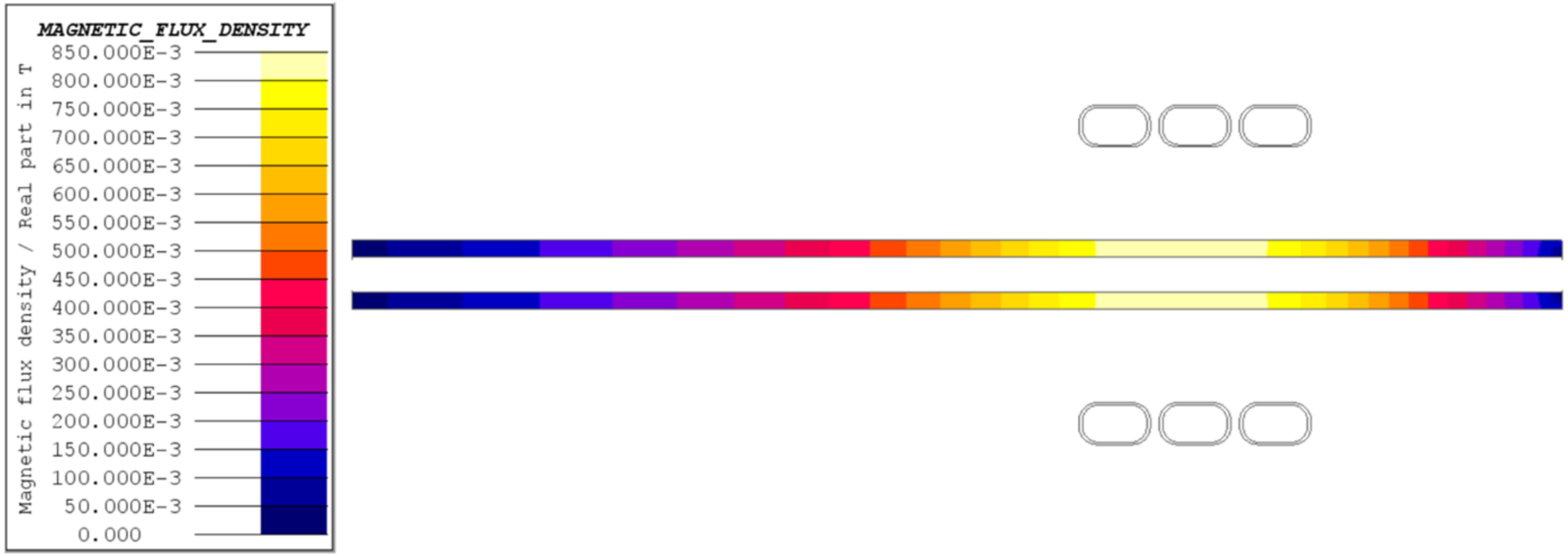


Initial Physical Testing

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

Accompanying Simulation

- The output frequency of the power supply, measured voltage and current of the coil, known geometry of the coil, and impeder mass can be used to create an accurate simulation of the process
- By using the documented magnetic properties of the SMC materials, the achieved magnetic loading of the impeders in the test stand can be calculated



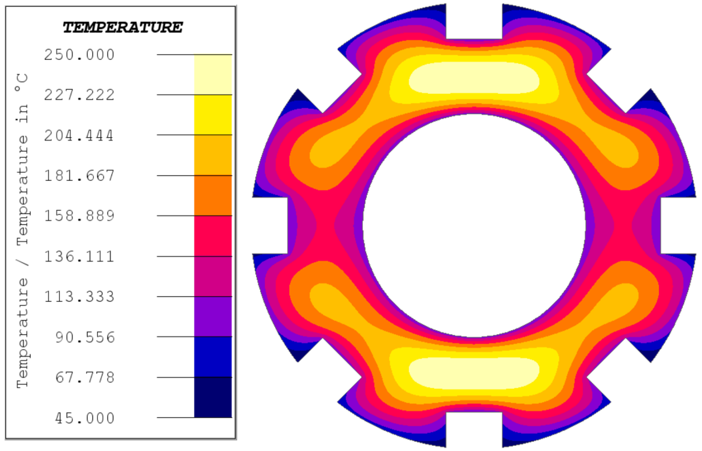
Completed Trials

- To establish the accuracy of the models, the simulated loading of the impeders and the published loss data for these SMC materials were used to estimate the losses in the impeder and compared to the measured energy in the impeder cooling water
- There is a good correlation between calculated and measured losses in the system
- No impeder failures were initiated when using normal cooling conditions

	10 mm				12 mm				14 mm				19 mm			
	f (kHz)	B (T)	Measured Loss (kW)	Simulated Loss (kW)	f (kHz)	B (T)	Measured Loss (kW)	Simulated Loss (kW)	f (kHz)	B (T)	Measured Loss (kW)	Simulated Loss (kW)	f (kHz)	B (T)	Measured Loss (kW)	Simulated Loss (kW)
559O	265	0.81	1.2	1.7	358	0.41	0.6	0.8	247	0.68	1.3	2.0	254	0.59	2.1	3.1
559H	270	0.71	0.9	1.2	362	0.53	0.9	1.1	251	0.58	1.0	1.3	258	0.48	1.6	1.8
50	316	0.69	2.0	1.9	403	0.47	1.1	1.5	304	0.57	2.4	2.2	257	0.52	3.4	3.0
75	312	0.79	2.1	2.2	308	0.77	2.3	2.4	300	0.66	2.2	2.6	255	0.60	3.2	3.5
A	304	0.88	3.5	3.6	333	0.82	4.2	4.3	290	0.70	4.0	3.8	245	0.59	4.9	4.4

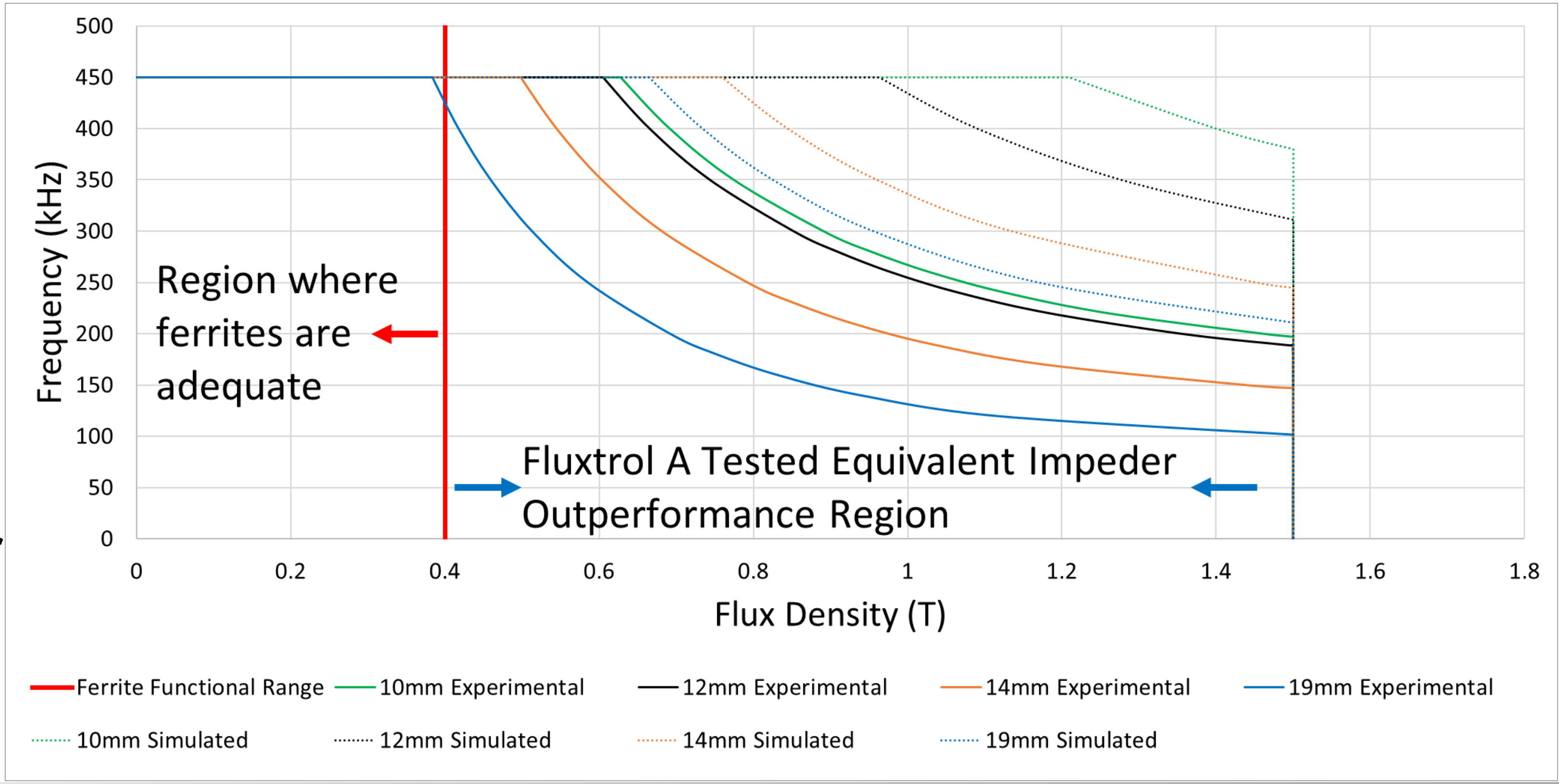
Simulated Operational Window Limits

- 2D thermal simulations were performed to investigate what theoretical limit of impeders made of SMC materials could survive provided cooling like that experienced in a tube mill
- The cooling boundary was set to a convection coefficient of 30000W/m2K with an average cooling water temperature of 40°C
- The loading of the impeder was increased until the steady state operating temperature of the impeder exceeded 250°C which is the published long-term operating temperature for these materials
- This image shows a cross-section of a 10mm Fluxtrol A impeder with loading equivalent to 1.4T at 400kHz



Experimental and Simulated Operational Windows

- This graph shows the experimentally validated regions with solid lines and theoretical limits with dotted lines for each size of impeder
- Computer simulation predicted that the tested impeders could survive with significantly higher magnetic loading than was tested for all conditions
- These results agree with the experimental test data as no impeder failures were achieved with normal cooling

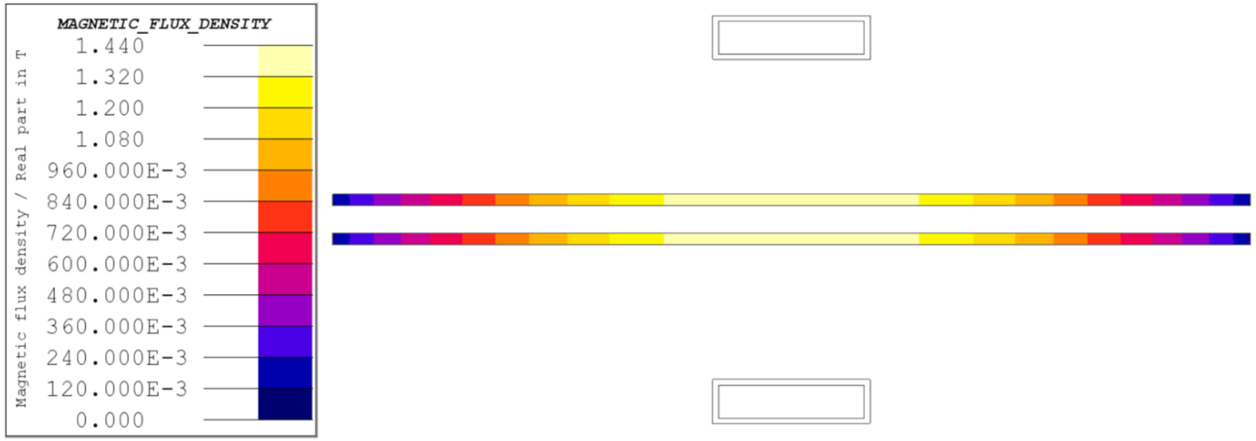


Test Stand Improvements

- To reach these simulated values the test stand was upgraded:
  - Induction coils were made to tune at higher loading, while also having improved buss work for proper cooling of the coil locations for measurement hookup
  - A 40kW 135-400kHz power supply was procured that has a 700Vrms upper limit as opposed to the 25kW power supply’s 500Vrms limit
  - A chiller was procured to supply the impeder cooling water to control the flowrate and temperature
- All these factors combined lead to a much more accurate calculation of the magnetic field the impeder is exposed to and the associated losses at the set frequency and field strength

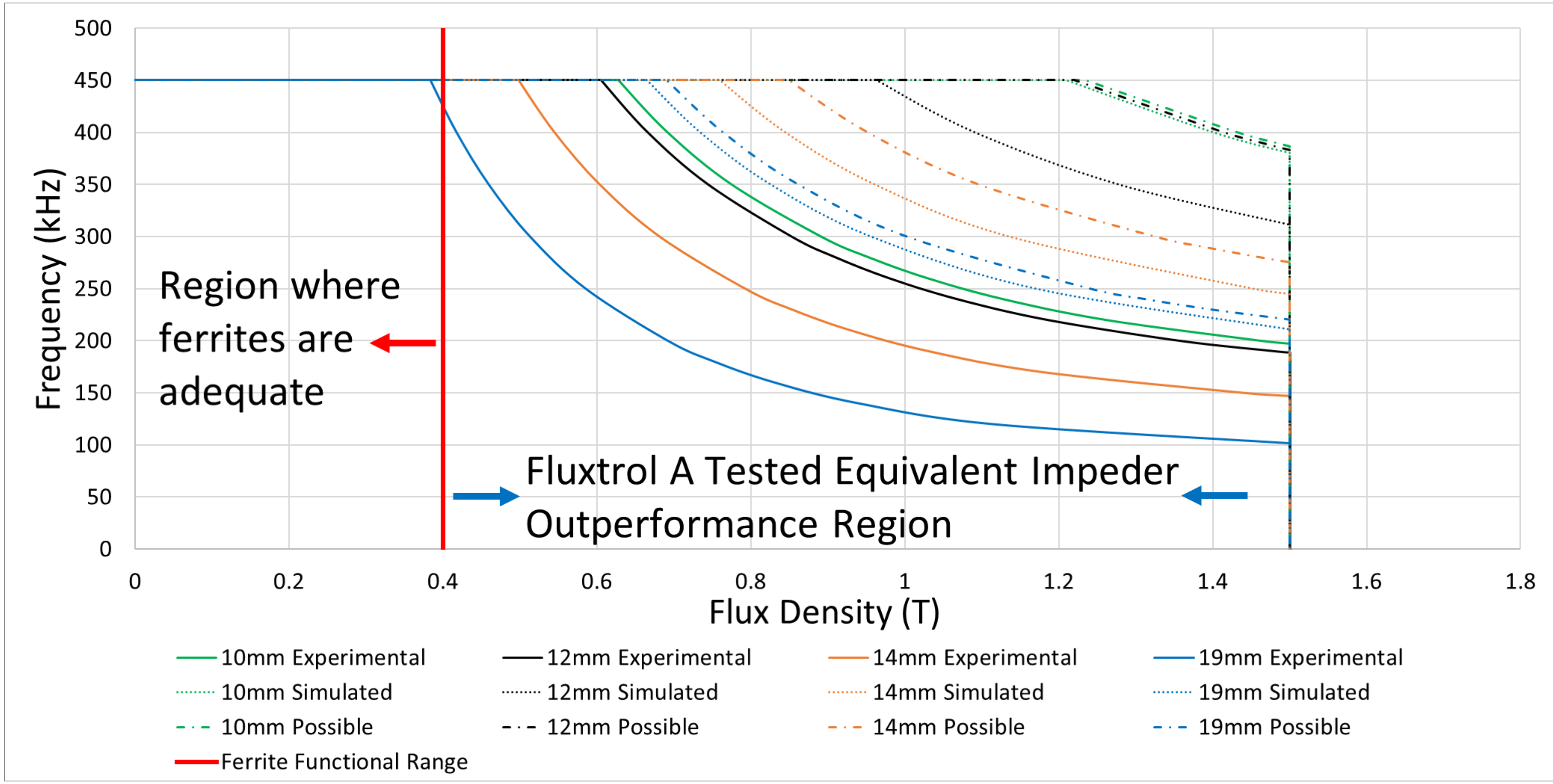
Revised Test Stand Limits

- Two coils were designed for use with the system
- The goal of the first coil is to create magnetic loading conditions like those tested in previous research, while the second coil was designed to get the magnetic loading of the impeders above the predicted failure points of the impeders
- The coil geometry found to tune nearest to the 700V, 3600A limits of the power supply at 400kHz was a single turn coil 35mm long with an 74mm ID
- Shown is a 2D axisymmetric simulation for a 10mm impeder with a potential maximum loading for Fluxtrol A using this coil



Revised Test Stand Limits

- This graph depicts the new achievable loadings with this improved test stand
- In order to test at and above the theoretical limits of these Fluxtrol A impeders a new set of trials is planned



Future Work

- The size of the impeder to be tested was limited to sizes under 1” in diameter, as tube welding systems operating with this sized component are most likely to be in a state of saturation
- Based on commercially available sizes, the impeders sized run in the currently planned trials is 10mm, 12mm, 14mm, and 19mm
- The impeders tested were all made of Fluxtrol A, as previous testing made it clear that this material is capable of withstanding the highest loading due to its high saturation flux density and reasonable losses and thermal characteristics
- While initial comparisons will use the standard fluted impeder geometry, work is also planned to improve this geometry to further expand the operational windows SMC impeders

Conclusions

- Soft magnetic composite impeders have shown the potential to significantly improve the performance of inductive tube welding systems where the ferrite impeders being used are in saturation
- The drawback of the earlier studies is that they were not able to identify the upper limit of where the materials could perform, and there were also varying degrees of correlation between the measured and calculated values for magnetic losses under some conditions
- Computer simulation was used to predict the upper bound of performance for 10, 12, 14, and 19mm impeder cores constructed from Fluxtrol A
- An upgraded test stand has been recently constructed and further trials to test these upped bounds and expand the operational window of impeders made of SMCs will be conducted in 2023

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Questions?

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