



Soft Magnetic Composite Impeder Geometry Optimization

10/16/2023

www.fluxtrol.com



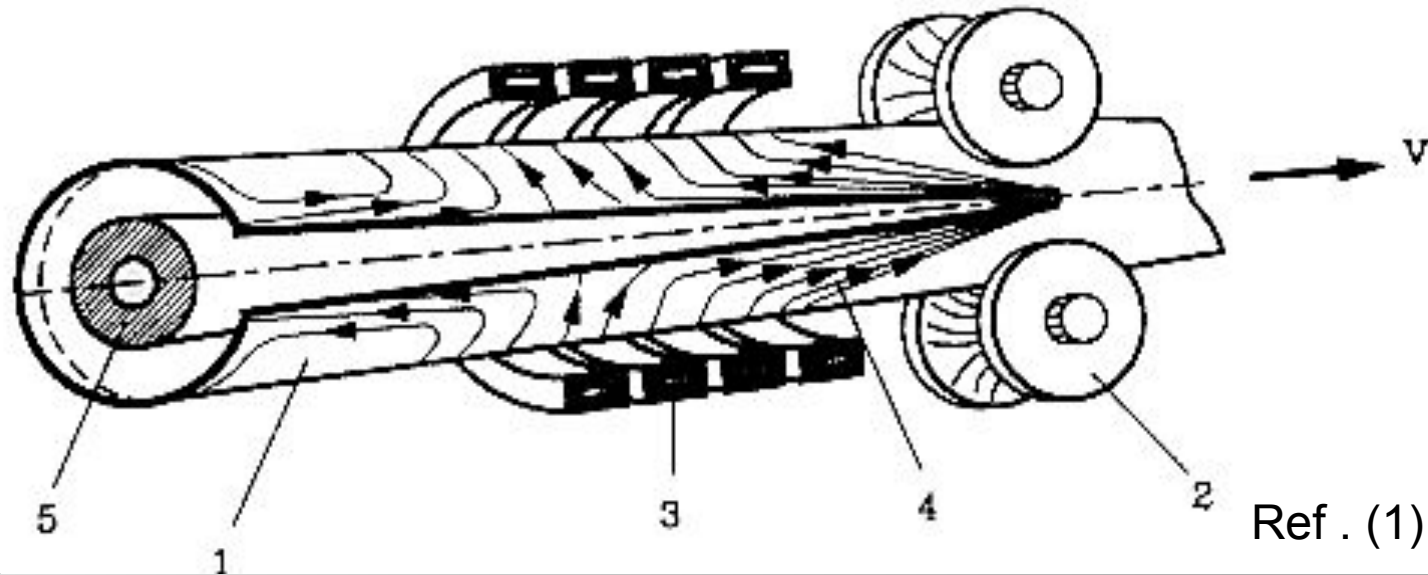
INTERNATIONAL MATERIALS,
APPLICATIONS & TECHNOLOGIES
2023

Overview

- The Induction Tube Welding Process
- Previous work
- Test Stand Improvements
- Impeder Geometry optimization
- 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
- 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)

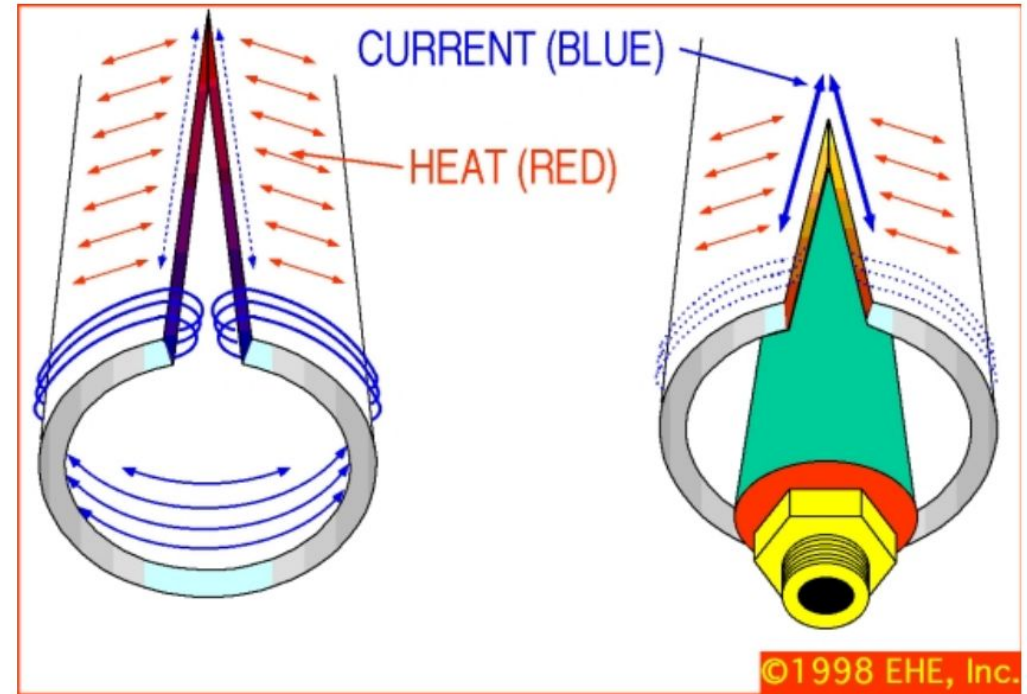


What is an Impeder?

- A magnetic concentrator fixtured within the forming tube that directs current flow
- There are two major competing current pathways around the tube, along the weld vee and around tube ID
- Impeder raises impedance of ID path, forcing current to weld vee



Ref . (2)



Ref . (3)

Energy Savings Opportunity with Improved Impeder Materials

- Case setups :
 - ~400kHz 100-300kW power supply
 - 19-20mm OD steel tube
 - 1-3mm thick wall
 - 9-10mm OD impeder
- **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



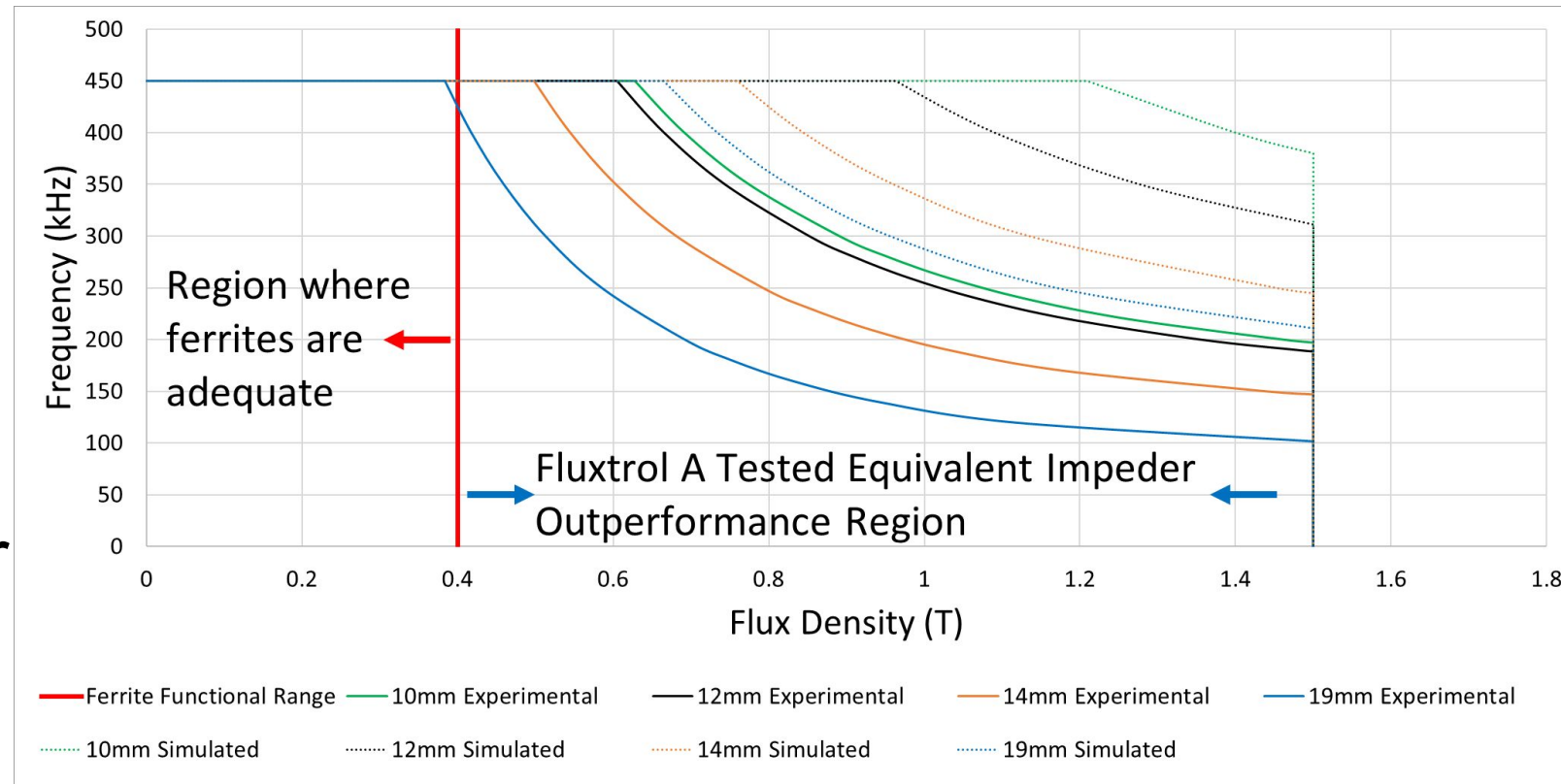
Completed Trials

- To establish the accuracy of the models, the simulated loading of the impellers and the published loss data for these SMC materials were used to estimate the losses in the impeller and compared to the measured energy in the impeller cooling water
- There is a good correlation between calculated and measured losses in the system
- No impeller 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

Experimental and Simulated Operational Windows

- This graph shows the experimentally validated regions as solid lines and theoretical limits as dotted lines for each size of Fluxtrol A impeder
- Computer simulation predicted that the tested impeder 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



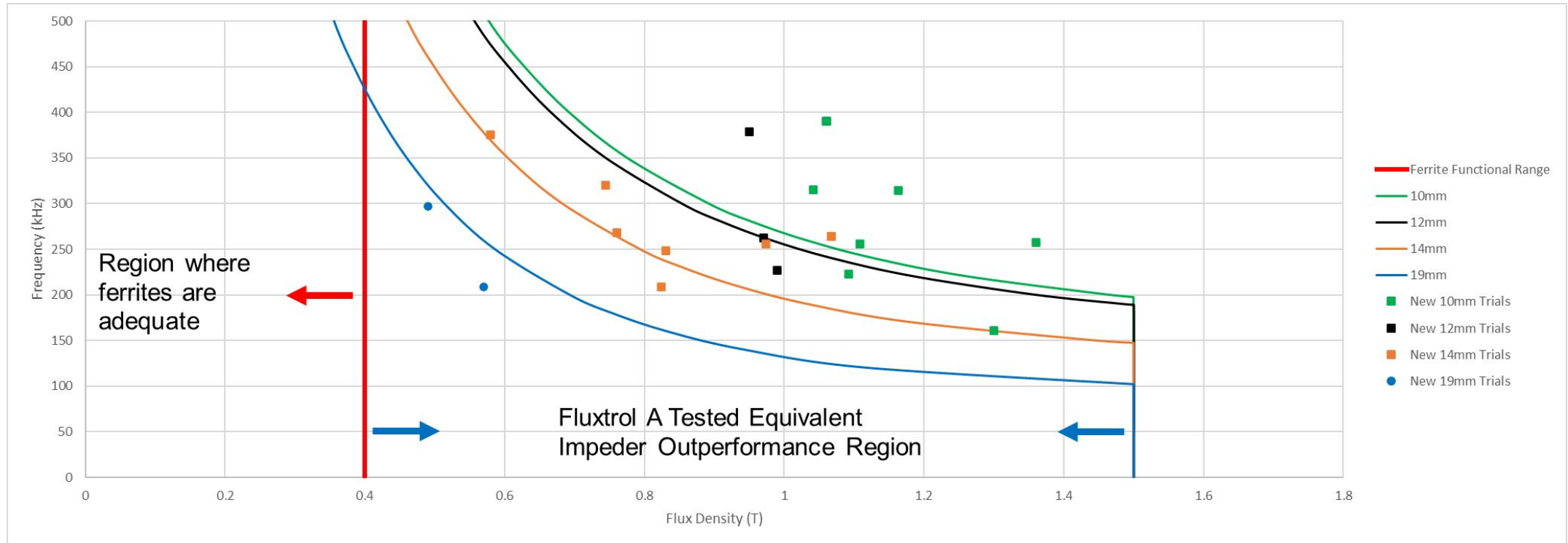
Improved Test Stand Trials

- The previous trial data was of the highest survivable loading of each impeder and extrapolating that point to create an operational window across all frequencies and magnetic loadings
- Using the improved test stand a greater number of samples and conditions have been tested to create an operational window from many points
- A focus has been put on testing Fluxtrol A as this material offers the largest possible improvement to magnetic loading compared with ferrites due to its 1.4T saturation flux density
- For the smallest impeder sizes, magnetic flux densities near the saturation flux density of the material were achieved on the improved test stand
- Testing is ongoing to achieve even higher magnetic loadings on the fluted impeder samples and to potentially initiate failure where expected

	10 mm	12 mm	14 mm	19 mm
200kHz	1.30	0.99	0.83	0.57
300kHz	1.36	0.97	0.97	0.49
400kHz	1.06	0.95	0.58	X

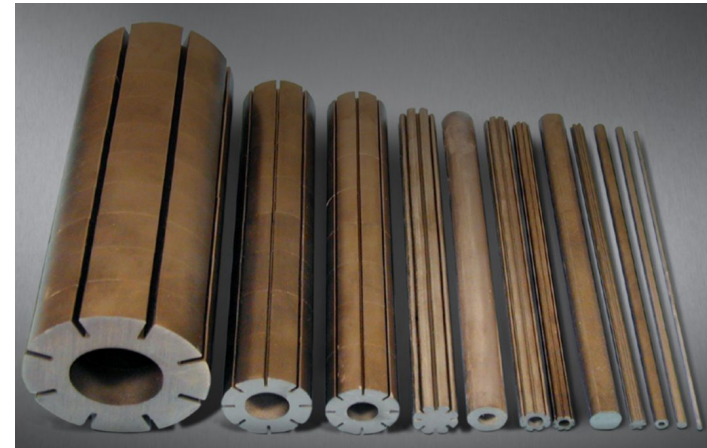
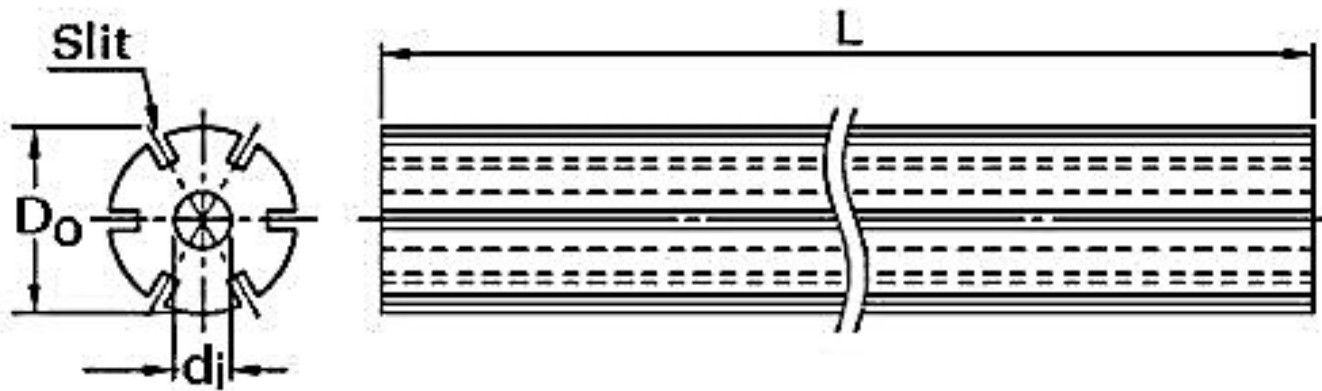
Updated Operational Range

- This graph shows the experimentally validated regions with solid lines with associated trials as points in the same color
- These results were similar to those obtained on the Original test stand as tuning limits of the power supply were reached for the larger impeder sizes



Impeder Geometry

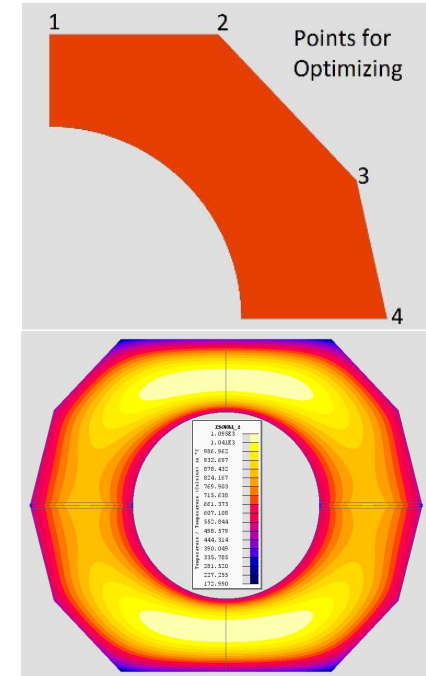
- There are a variety of potential impeder geometries, but the most common form consists of a cylinder with flutes on the outer diameter
- Soft Magnetic Composite (SMC) impiders were made with the same geometry for direct comparison and showed improvement in magnetic loading capacity
- While this geometry may be ideal for an extrudable isotropic ferrite material, SMCs are anisotropic and, in most cases, need to be machined, meaning optimizing the geometry for SMC impiders may lead to further improvements for the system as well as lower manufacturing costs



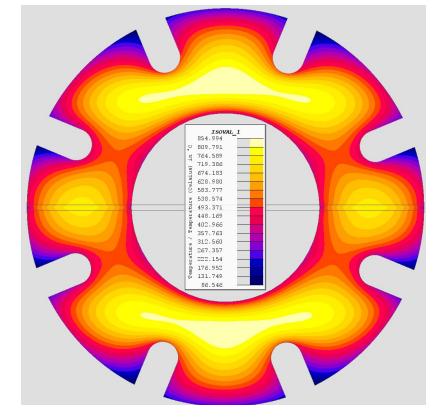
Ref . (2)

Faceted Impeder Optimization

- 2D thermal simulations were done comparing the original fluted geometries for each size to a potential faceted design
- A parameterized model was run adjusting the 4 points determining the faceted geometry with the end goal being a more even distribution of heat, rather than the single hot spot as can be seen in the fluted design
- The following design constraints were used to ensure the same magnetic loading would be achieved and that the same impeder casing could be used for each design
 - Same cross-sectional area for the same volume of concentrator
 - Same magnetic loading and associated heating
 - Same ID for the central brass cooling line
 - Same maximum OD to fit within the casing
 - All Calculations run at Saturation at 400 kHz (worst case scenario)



19mm Faceted



19mm Fluted

Faceted Impeders Same Cross-Section – Fluxtrol A 400 kHz

- The total magnetic capacity of an impeder is the product of the flux density and the cross-section
- If the cross-section and material are the same, then the magnetic performance of the impeders should be the same
- For smaller diameter impeders, the performance of the faceted impeders is better due to limited physical dimensions
- However, for larger impeders, the fluted impeders can withstand higher loadings due to heat transfer considerations

All cases above thermal limit
of Fluxtrol A at this loading

	10 mm	12 mm	14 mm	19 mm
Fluted	384°C	502°C	673°C	855°C
Faceted	373°C	471°C	622°C	1010°C

Faceted Impeder Trials

- Same Cross-Section faceted impeder have been fabricated and testing has recently begun
- Trials to date have shown nearly identical magnetic behavior of the fluted and faceted designs as expected
- No thermal failures have been observed in the trials run to date, although the magnetic loadings have not reached the levels that failure would be expected
- Additional testing is planned for the coming months

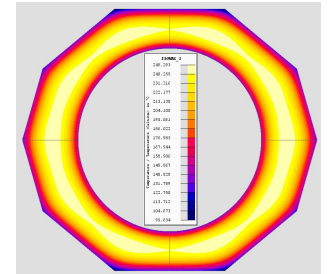
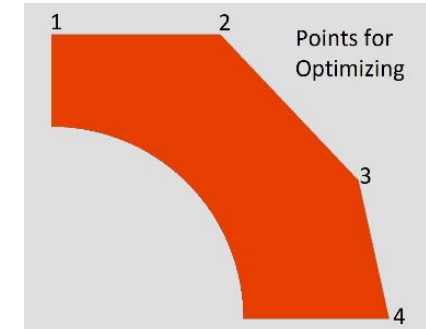
Faceted Impeder Optimization – Reduced Cross-Section Fluxtrol A 400 kHz

- The total magnetic capacity of an impeder is the product of the flux density and the cross-section
- If the cross-section is reduced somewhat, higher magnetic capacities can be achieved, which are still much higher than ferrites with saturation flux density of 0.4-0.5 T
- This is especially true for the larger sizes of impeders where the wall thickness and distance to cooling were greater
- With a small reduction in cross-section, operating temperatures can be reduced, and in the case of the faceted, theoretically operate at saturation

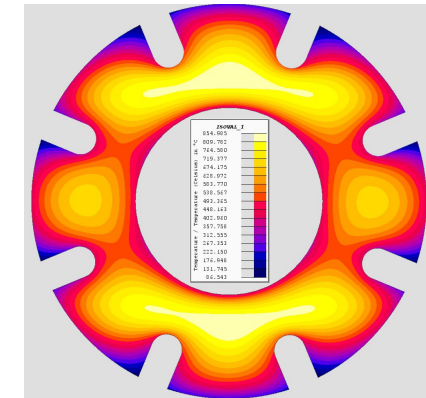
	10 mm	12 mm	14 mm	19 mm
Fluted	384°C	502°C	673°C	855°C
Faceted	243°C	320°C	432°C	690°C

Further Optimization

- The faceted geometry optimization was initially constrained to have the same cross-sectional area as the fluted geometries, but as SMCs have many times higher magnetic flux densities, it was thought to be possible to make an “Invincible” geometry that could run at saturation without overheating
- This would involve exploring other material grades with lower permeability and losses than Fluxtrol A, other geometrical designs
- This would reduce the energy savings at lower magnetic loadings, but allow for reliable operation at higher magnetic loadings, while also eliminating the possibility of thermal destruction of the SMC impeder



19mm “Invincible”



19mm Fluted

“Invincible” Geometries

- The optimization was carried out for each Ferrotron 559H Original impeder size
- The impeders were run at saturation and the geometries were adjusted until maximum temperatures of 250°C were achieved
- Below is a table with the remaining fractional volume of these “Invincible” geometries compared to the original fluted design
- This gives an idea of the relative reduction in magnetic loading
- While there is a loss in potential magnetic loading, SMCs have saturation flux densities of 2-3 times that of the traditional ferrites, which can still make these designs viable from an efficiency standpoint
- Additionally, these “Invincible” designs can run without the risk of overheating would be a benefit in systems where there is an advantage for energy savings, but not an opportunity to increase the line speed of the tube welding process

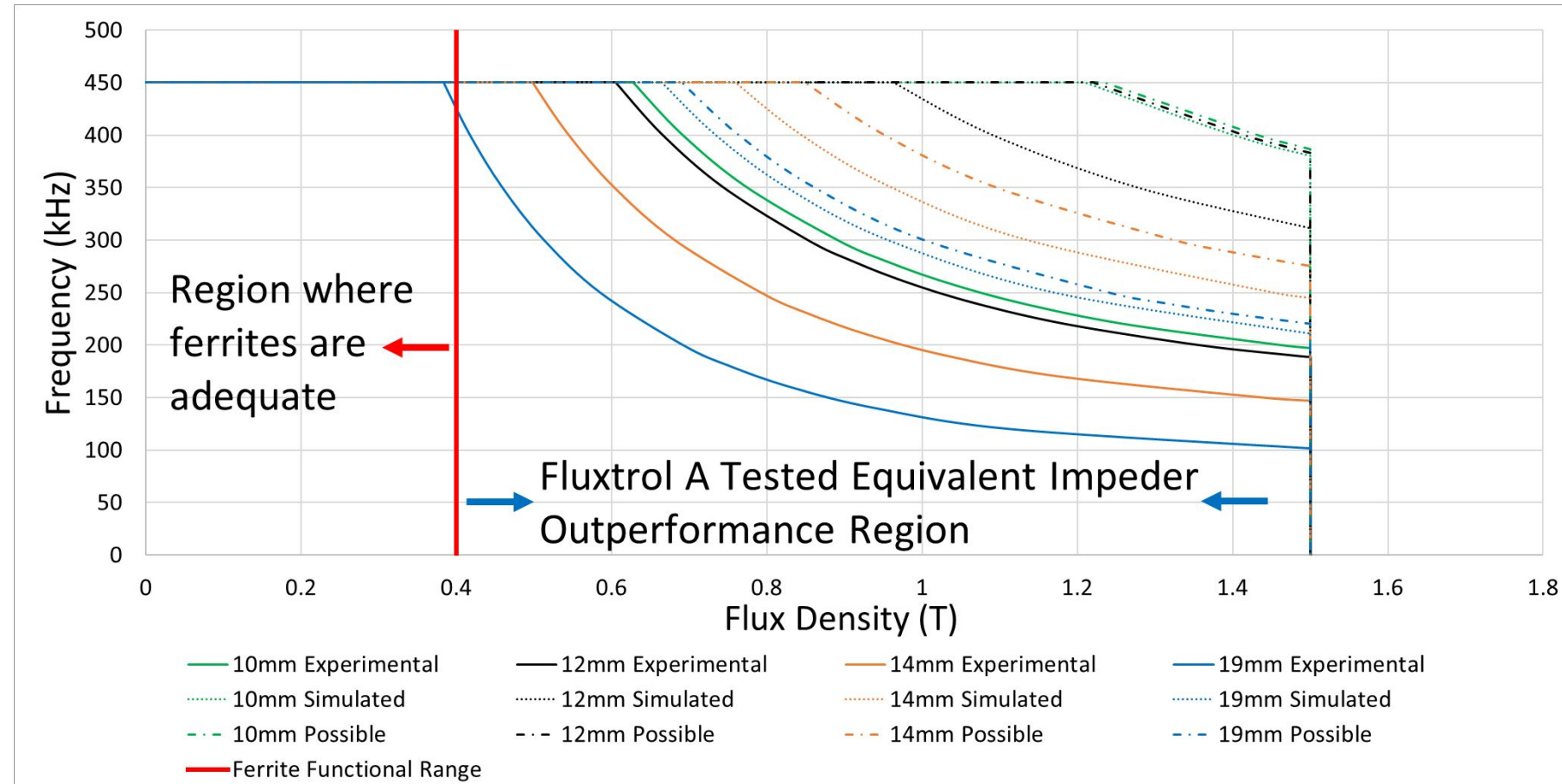
10 mm	12 mm	14 mm	19 mm
1	0.81	0.66	0.44

Conclusions

- It has been shown experimentally that SMC materials are able to carry magnetic loads 2-3 times that of ferrites
- Experiments also show that there is further room for improvement for both magnetic carrying capacity of SMC impellers of larger sizes
- Simulations show that for smaller impellers, a faceted geometry is better able to dissipate the heat in an SMC impeller compared with the fluted design
- To definitively show the improvements of SMC impellers over traditional ferrites, as well as the improvements of the faceted design over fluted for SMC impellers, the tuning limits of the power supply and inductor need to be overcome

Future Work

- Work is being done to adjust the tuning balance for the power supply and inductor to be able to get full power out of the machine
- This graph depicts the new achievable loadings with the planned improvements
- Additionally, the “Invincible” geometries will be constructed and tests run on this improved test stand to determine if they can run at saturation





Q&A

References

- 1) Image is taken from UIE book “Induction Heating – Industrial Applications”
- 2) Image is taken from EHE US Product Catalog 2018
- 3) Image is taken from Tube & Pipe Technology “Optimizing Efficiency in HF Tube Welding Processes”

(1)