HES-19 International Symposium on Heating by Electromagnetic Sources

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Padova, Italy

International Symposium on Heating by Electromagnetic Sources

Magnetic Core Loss Behavior At High Fields in Magnetic Materials

May 24th 2019

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Background

- Soft Magnetic Composites (SMC's) are widely used in induction heating applications
- Having accurate data for magnetic core losses is critical for computer modelling in challenging applications
- Current methods for measuring core loss at higher frequencies have shown significant levels of variation trial to trial
- Current models for core loss do not agree with experimentally measured values over wide ranges of field strength and flux density

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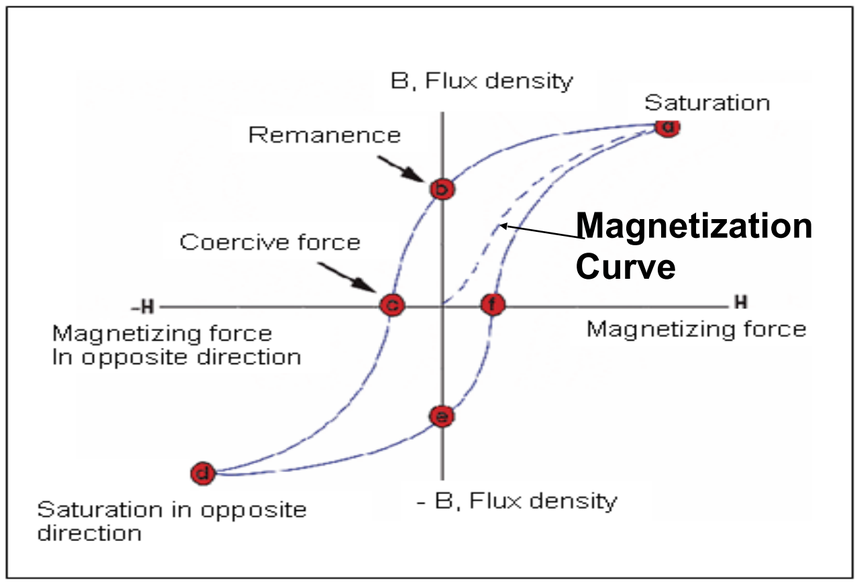
High Frequency Magnetic Core Losses

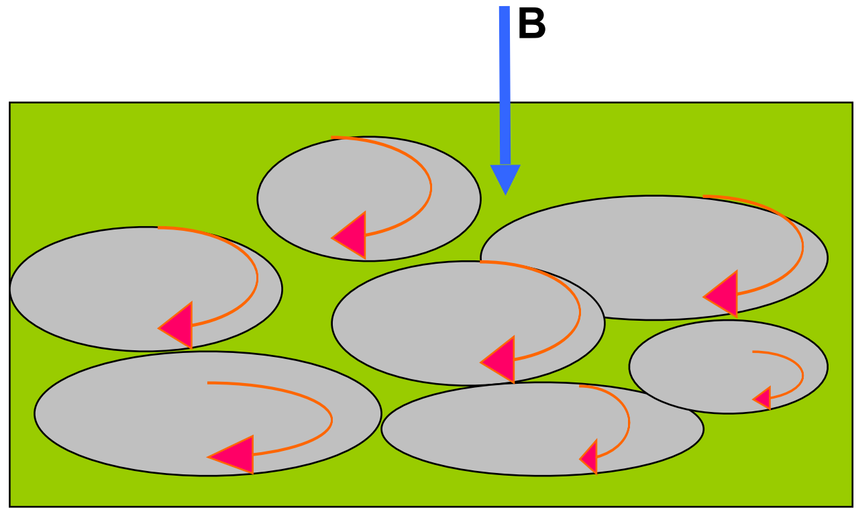
- Core Losses consist of 4 components
  - Hysteresis Loss
  - Eddy Currents in individual particles
  - Regional eddy current losses in a core
  - Global eddy current losses in the core
- Most common formula for approximation
  - Modified Steinmetz Equation -

$$P_v = k\, f^a B^b$$

- From a fundamental perspective, the formula should be (assuming good particle insulation) -

$$P_i = f \oint H\, dB + \frac{\pi^2 t^2 B^2 f^2}{6\rho d}$$





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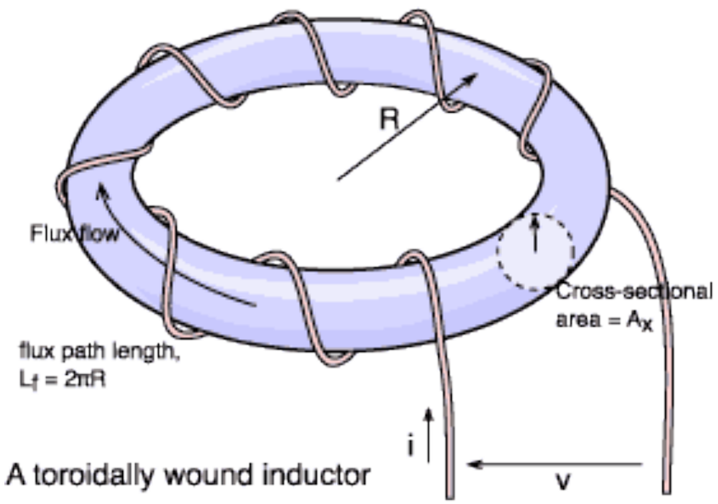
Current Standard Core Loss Measurement Techniques

- Typically made via calorimetric method with adiabatic and uniform fluid temperature assumption or by calculating slope of initial heating curve
  - Single point temperature measurement
- Torroidal core is typically wound with solid copper winding
- When turns number is reduced to reach higher flux densities, space factor for windings is low



http://info.ee.surrey.ac.uk/Workshop/advice/coils/force.html

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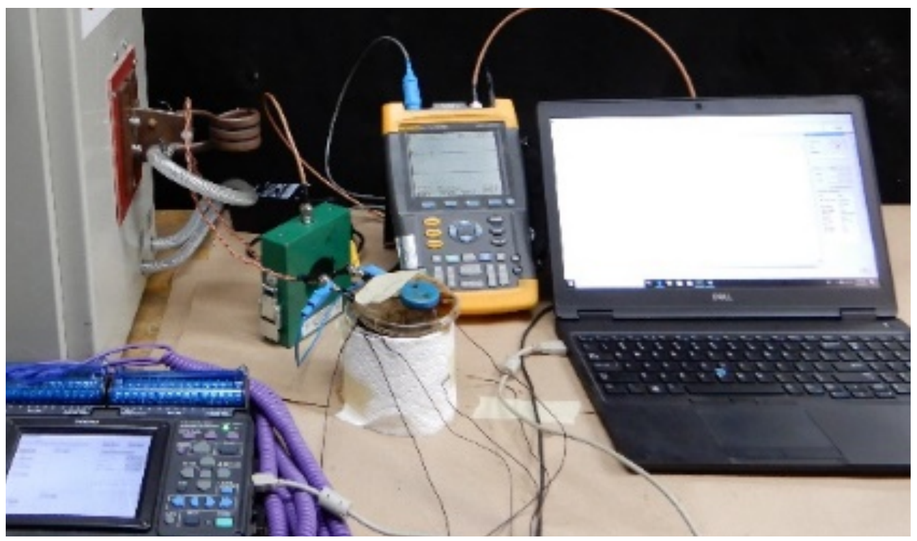
Improved Measurement Method

- Multiple point thermocouple measurement
  - 3 in fluid
  - 1 on OD of insulation
  - 1 on Upper surface of vessel
  - 1 a few inches from vessel
- Use of litz wire to reduce winding loss
- Multiple turns in parallel to maximize space factor
- Short leads tightly coupled to limit leads effect
- Inverse calculation of magnetic loss based upon cooling curve analysis
- High boiling point liquid to avoid phase transformation



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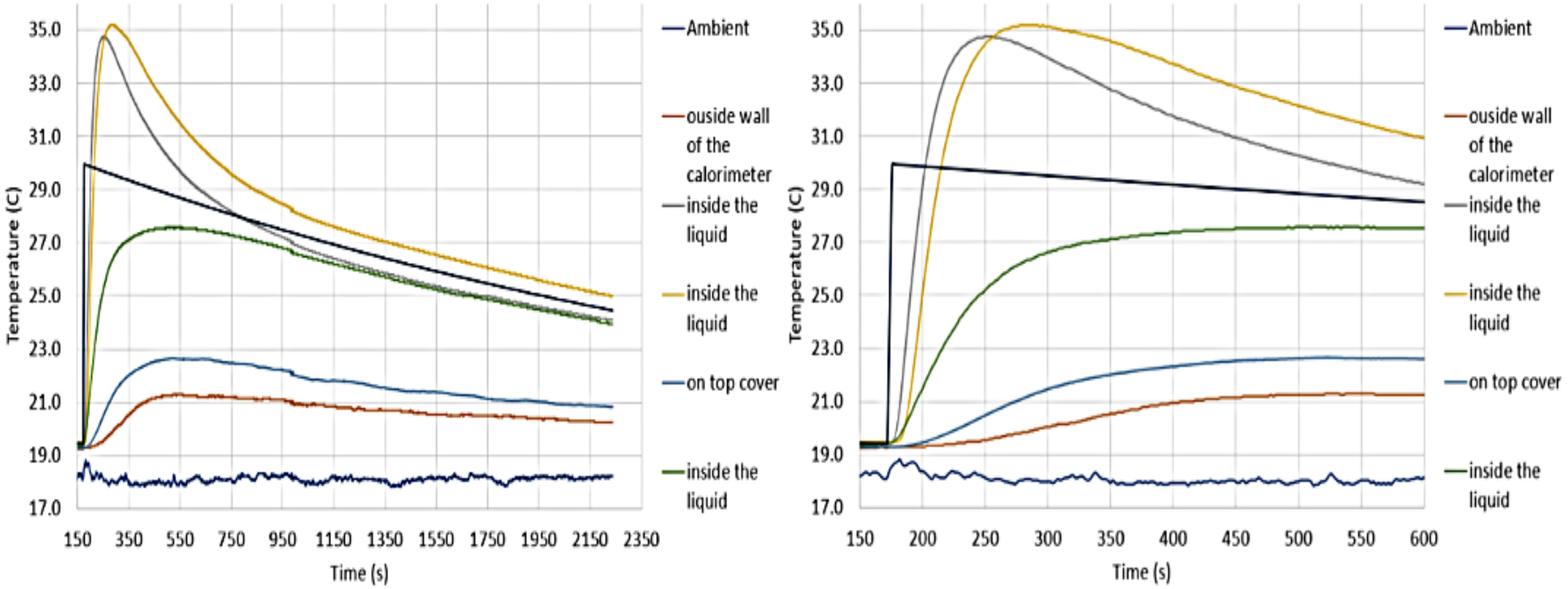
Distribution of Temperature in the System



- In this example, delta T varied 2 X, which would lead to error of 100% between two different measurements using standard calorimetric calculation
- Using slope method, the variation would be similar. Also, in all 3 cases it is significantly less than the inversely calculated value due to thermal lag in the system

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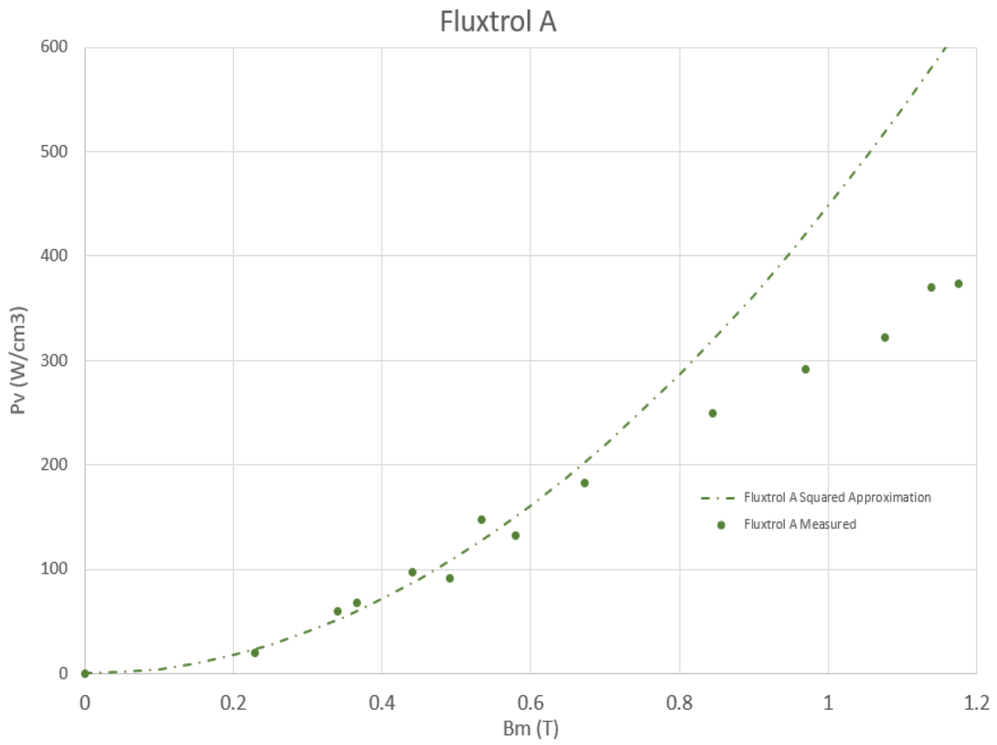
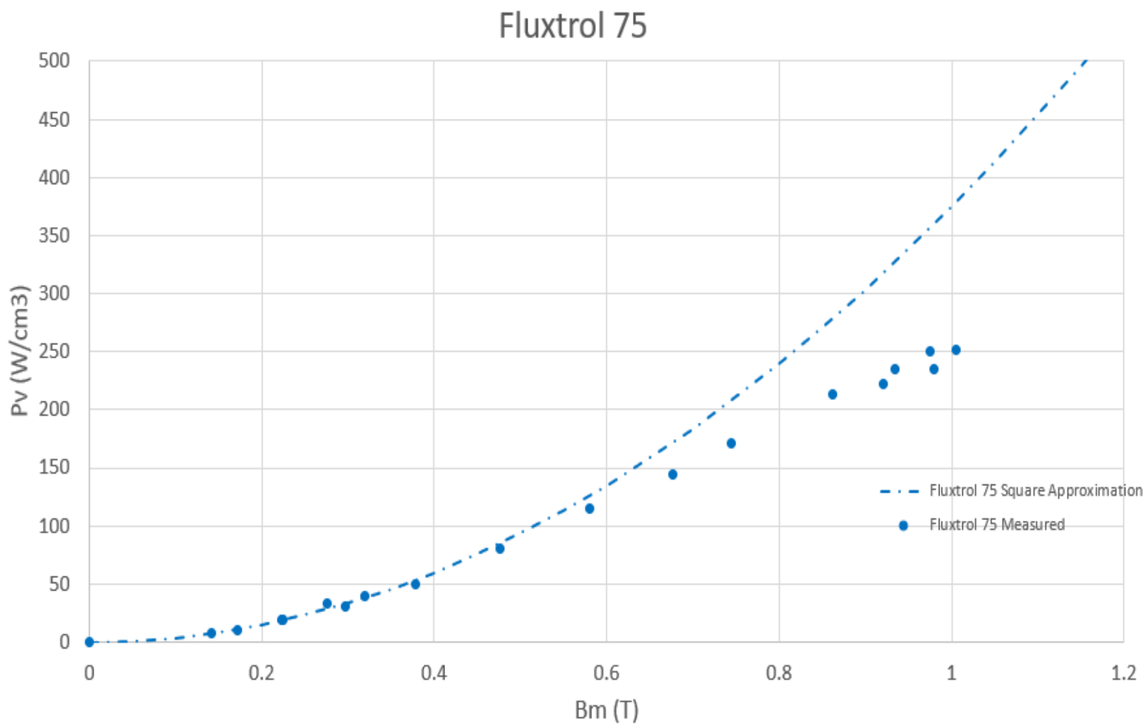
Loss Measurement for Fluxtrol A and Fluxtrol 75 at 150 kHz





- At low magnetic flux densities, the losses can be approximated well by B^2
- As flux density increases, core losses rise at a much slower rate
  - The declining rate of core losses is located where the magnetic permeability of the core is declining
  - Same trend observed at multiple frequencies

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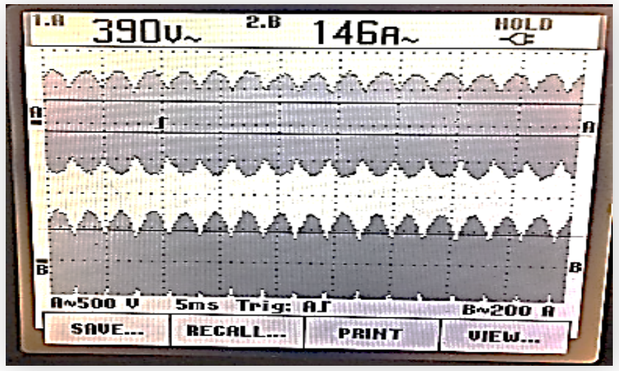
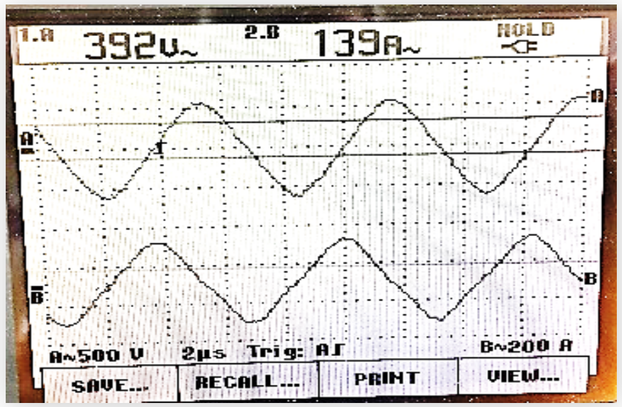
Notes About B_m Calculation for High Frequency Testing

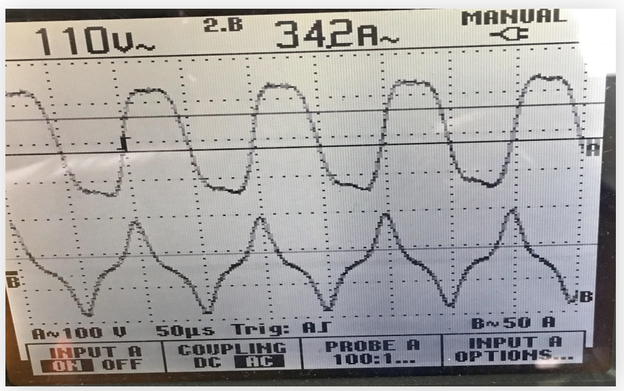
- Due to imperfect rectification, voltage/current values have a low frequency oscillation (typical for induction heating systems)
- As field levels increase, the magnitude of these oscillations increases
- Also, the shape of the current waveform goes from sinusoidal, to triangular, to strongly distorted as saturation is approached
- B_m calculated by multiplying the “Average” rms value by 1.414 to better match to simulation models, which assume constant rms signal



5 ms/div



2 μs/div



≈ 1.2 T @10 kHz

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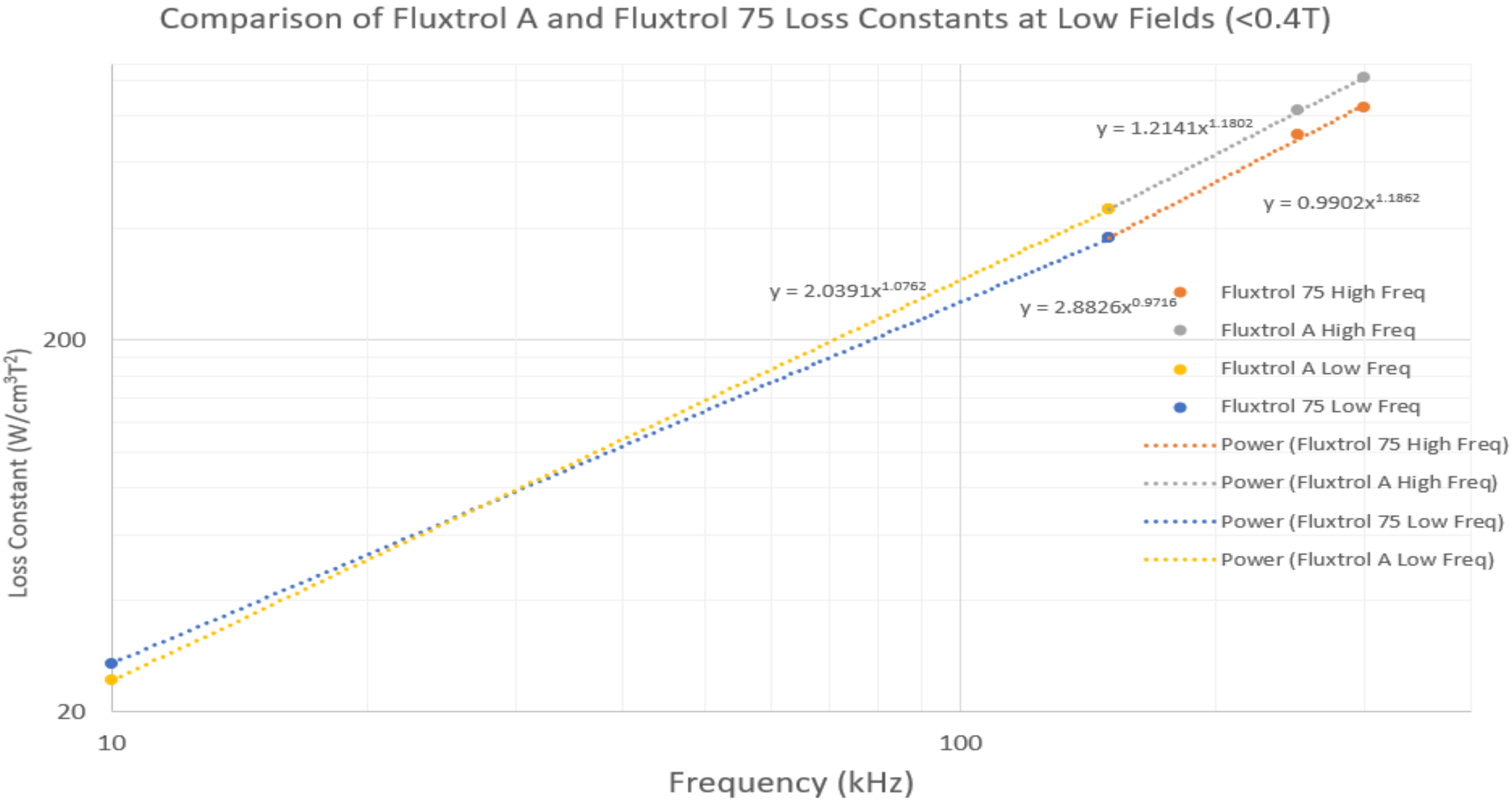
Effect of Frequency on “Low Field” Loss Constant



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Conclusions

- Current Models being used for core loss description do not accurately depict real behavior
- Current models for measurement of core loss can be highly inaccurate in some cases
- A new loss measurement/calculation method has been proposed
- A new model for core losses needs to be created taking into account magnetic non-linearity and multiple loss sources with different dependencies

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Future Work

- Work is currently underway to conduct these measurements for all of our materials over a wide range of frequencies and to update the database for our materials
- Work is underway in comparing the measurements at different frequencies and developing a mathematical function which can cover the full operating range of frequencies of our materials
  - Should have separate constants for eddy current and hysteresis loss
  - Function should account for magnetic saturation
    - Relationship should be similar, but different for eddy current and hysteresis

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Questions

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