Session 4b
Reass II

MULTI-MEGAWATT HIGH FREQUENCY POLYPHASE NANOCRYSTALLINE TRANSFORMERS*

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Abstract

High frequency power transformer designs now provide a viable method to significantly reduce the physical size, weight, and footprint as compared to conventional 60 Hz power transformers. In addition, recent developments in transformer core materials also give the ability to operate at high flux densities (> 1T) with excellent efficiencies. These authors prefer amorphous nanocrystalline alloy that provides the highest flux swing and lowest loss in the 20 kHz frequency range. The amorphous nanocrystalline alloy is a glassy amorphous spin-cast material available in ribbon tapes from various vendors. The tapes are then wound into the desired shapes and then processed to achieve the nanocrystalline structure. A cut-core design gives a simple transformer fabrication and assembly topology without a significant loss of electrical performance. Further optimizations can improve efficiency and/or size, depending on the specific application or requirement.

High Frequency Nanocrystalline Transformers Are Over 150 Times Lighter And Significantly Smaller (At Same Power)

HVCM Transformer

- 150 kV, 20 KHz
- 20 Amp RMS
- 1 MW Average (3) Present Use
- 450 LBS for 3
- 3 KW Loss At 2 MW
- “C” Core Design (Parallel Windings)

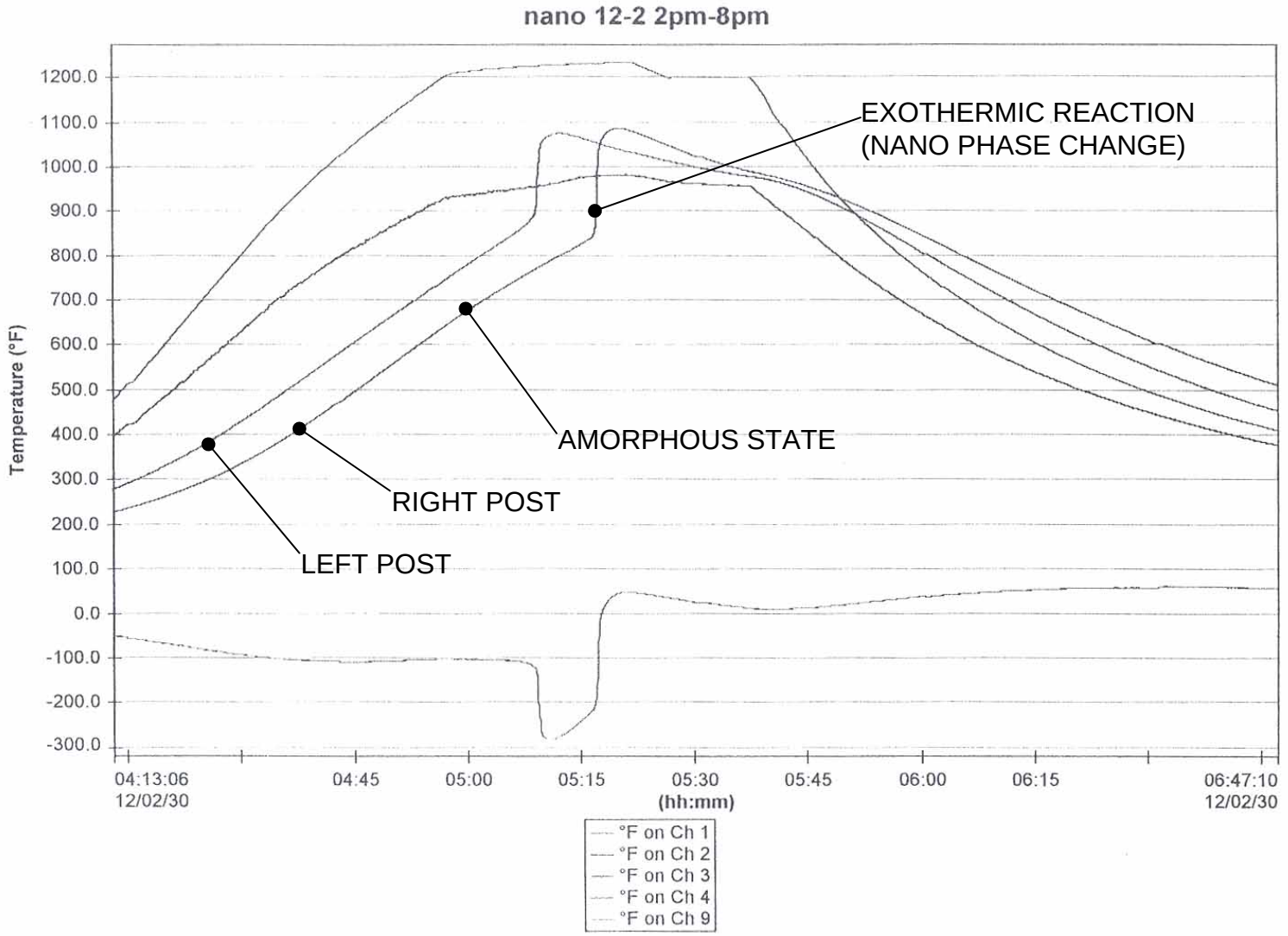
Typical H.V. Transformers

- 100 kV, 60 Hz
- 20 Amp RMS
- 2 MW Average
- 35 Tons
- ~30 KW Loss

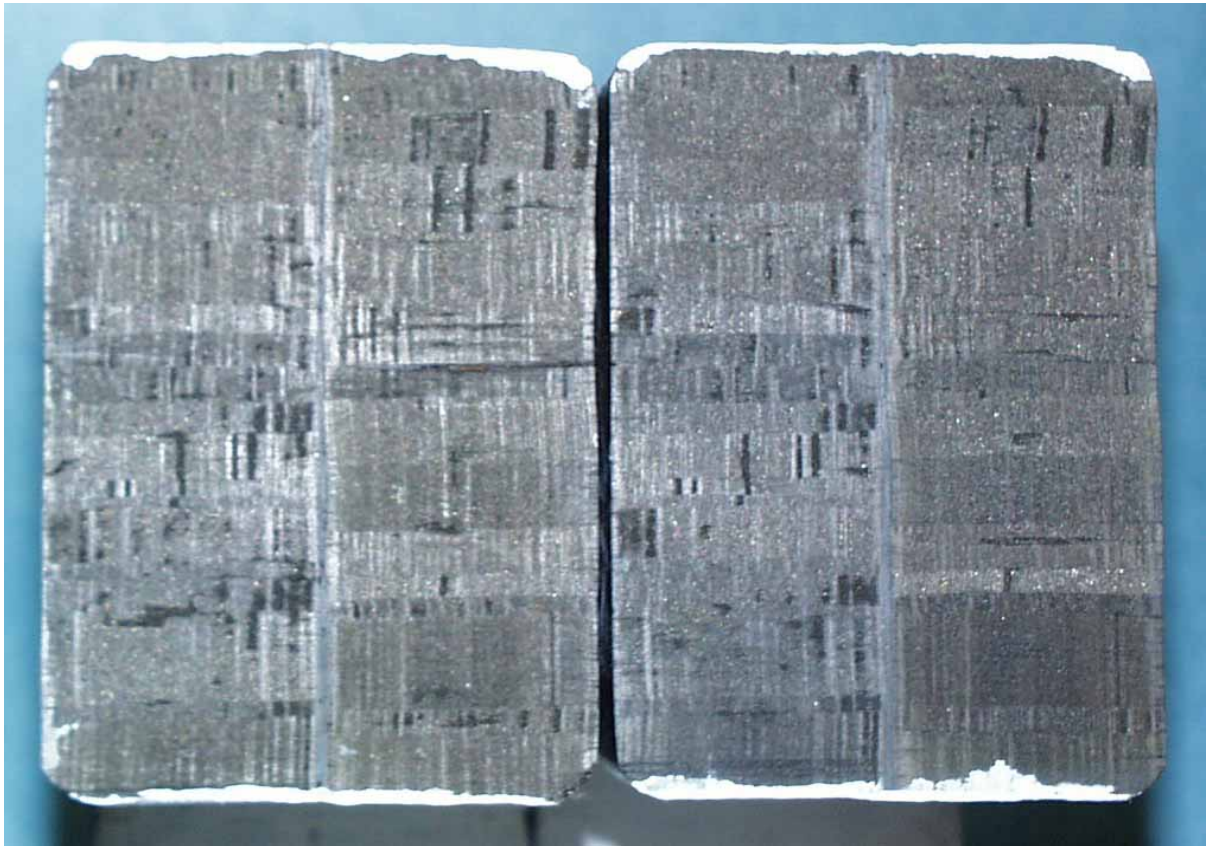
Nanocrystalline Transformer Development

- Funding Provided To Develop Manufacturing Processes
- Winding (Nano Shrinks ~1% During Processing)
  - Loose
  - Compressible Mandrel
- Process Regulation (Exothermic Reaction)
  - Temperature Control – Feedback Controlled Oven Temperature
- Stack Lamination Insulation
  - Wet Lay-Up
  - Dry
- Core Cutting
  - Water Jet, EDM, Diamond Saw
- Core Annealing
  - Dimensional Stability
- Pole Face Lapping, Etching
  - Pole Face Stack Resistance
  - Eddy Current Losses

Nanocrystalline Core Phase Change



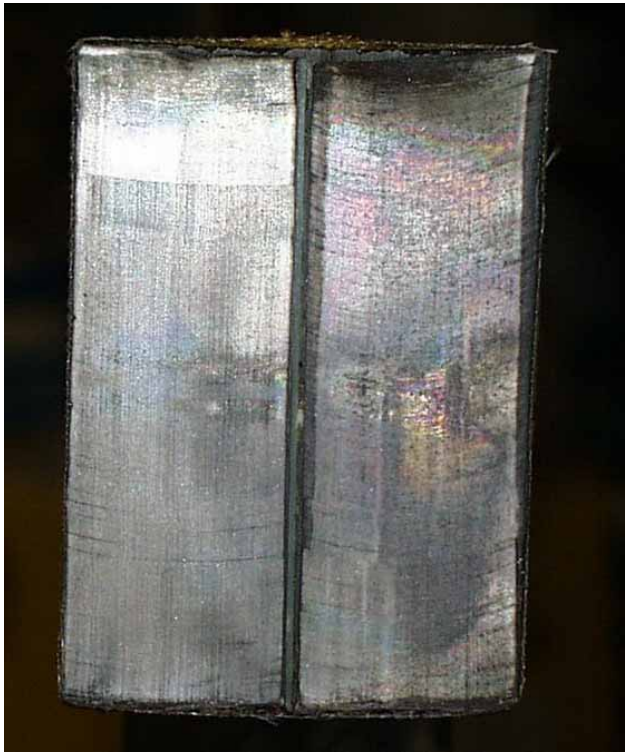
Russian EDM Cut Nano Core



- Not A Good Process
- Significant Pole Face Pitting

VacuumSchmelze Cores

- Loose Lay-Up
- Poor Dimensional Characteristics
- Low Stacking Factor
- Wet Lay-Up
- Fiberglass Tape For Mechanical Strength



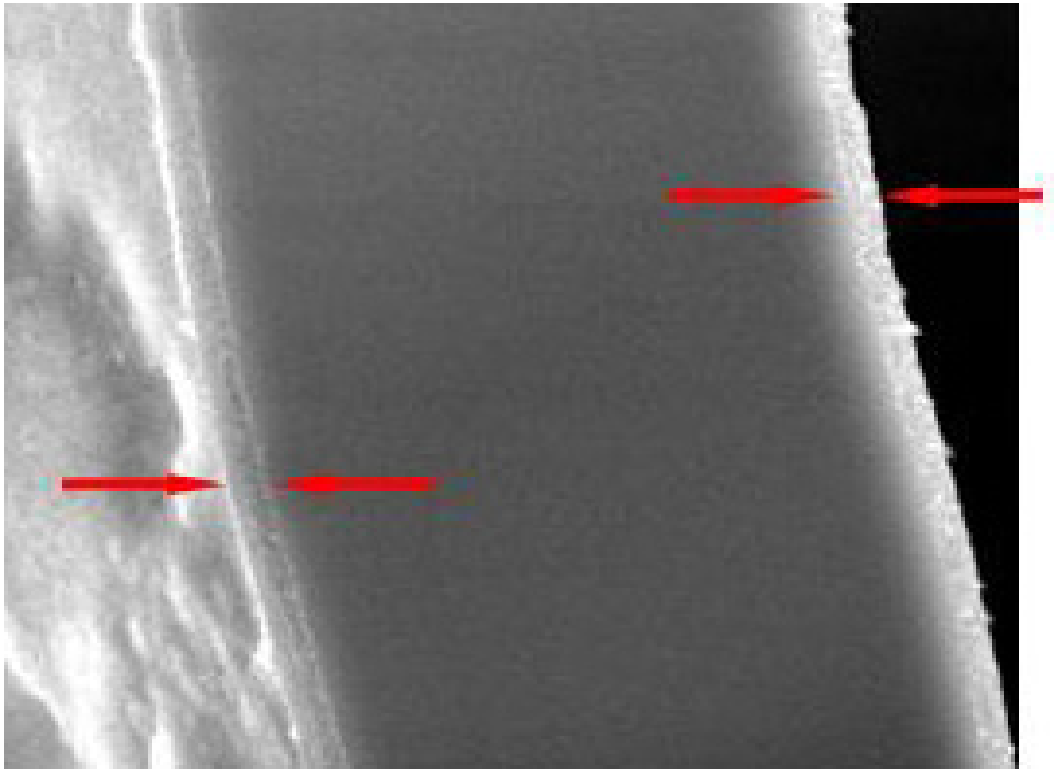
- Poor Adhesion
- Lamination Cupping
- No Pole Face Etching
  - Lower Pole Face Resistance

Nanocrystalline Transformer Development Results

Nano Material Characteristics

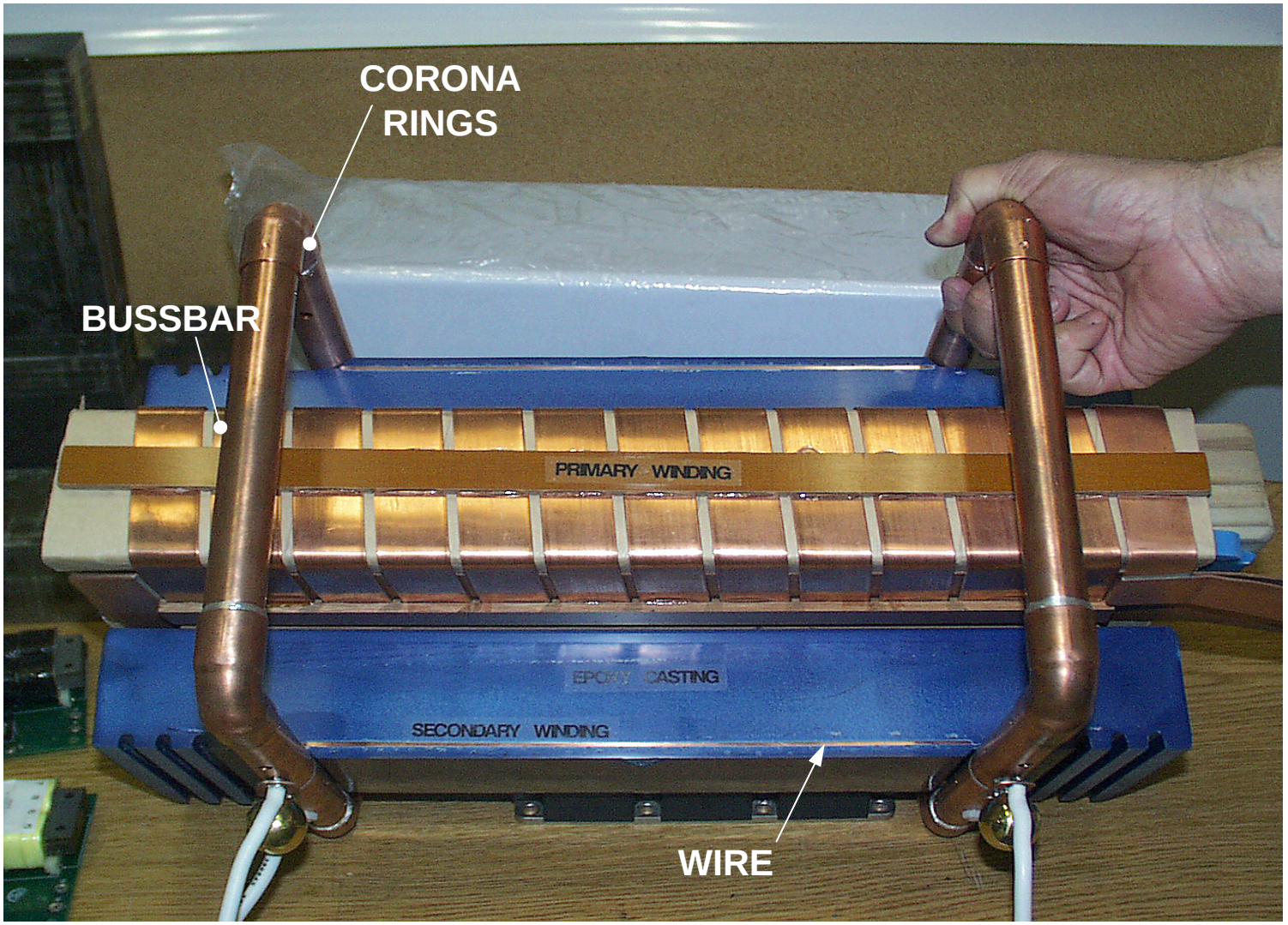
Mu	50,000
Lamination Thickness	.0007"
Lamination Insulation	<1 µM
Stacking Factor	~90%
Bsat	12.3 kG
Core Loss (our use)	~300 W
Core Weight (our use)	~95 lbs
Power (each core)	330 kW

Oxide Insulating Coating



- Near Zero Magnetostriction
  - No Significant Core Vibration Or Noise

Boost Transformer Winding Design (140 kV)



Recent Developments

- Wider Strip Width
  - Improved Core Geometries
- Improved Manufacturing
  - Better Experience Base
    - Better Mechanical Fabrication Techniques
    - Can Possibly Manufacture Exotic Shapes
- Improved Electrical Performance
- More Vendors
  - Japan
  - Russia
  - Germany
  - China

Advanced Transformer Geometry

- Polyphase Y
- Ring And Bar
- Triangle And Bar

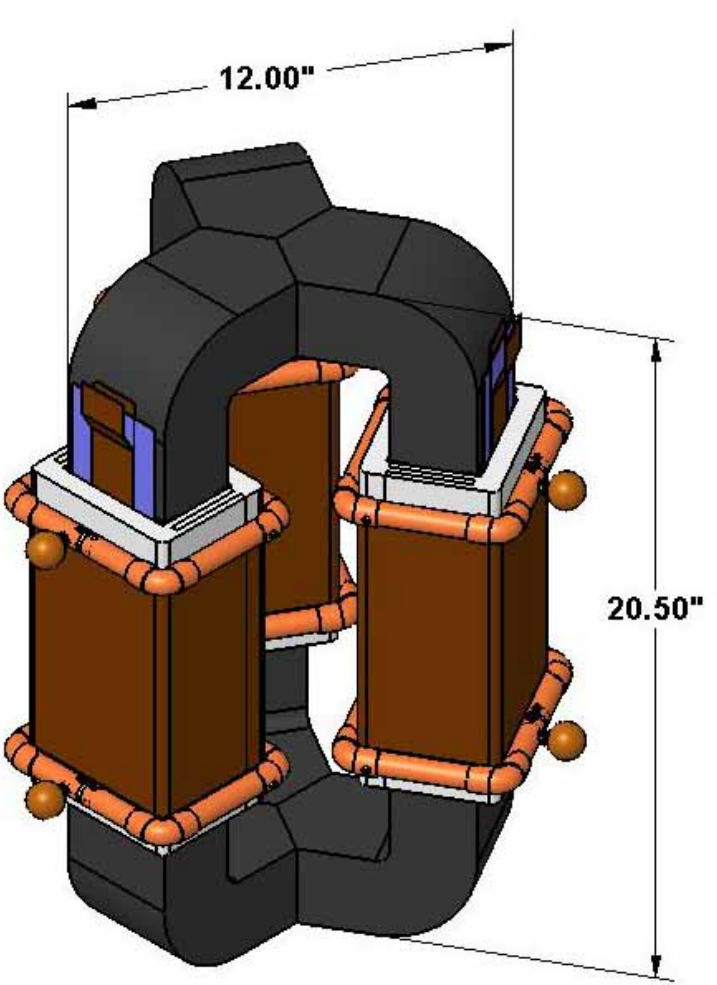
Polyphase Y

ADVANTAGES

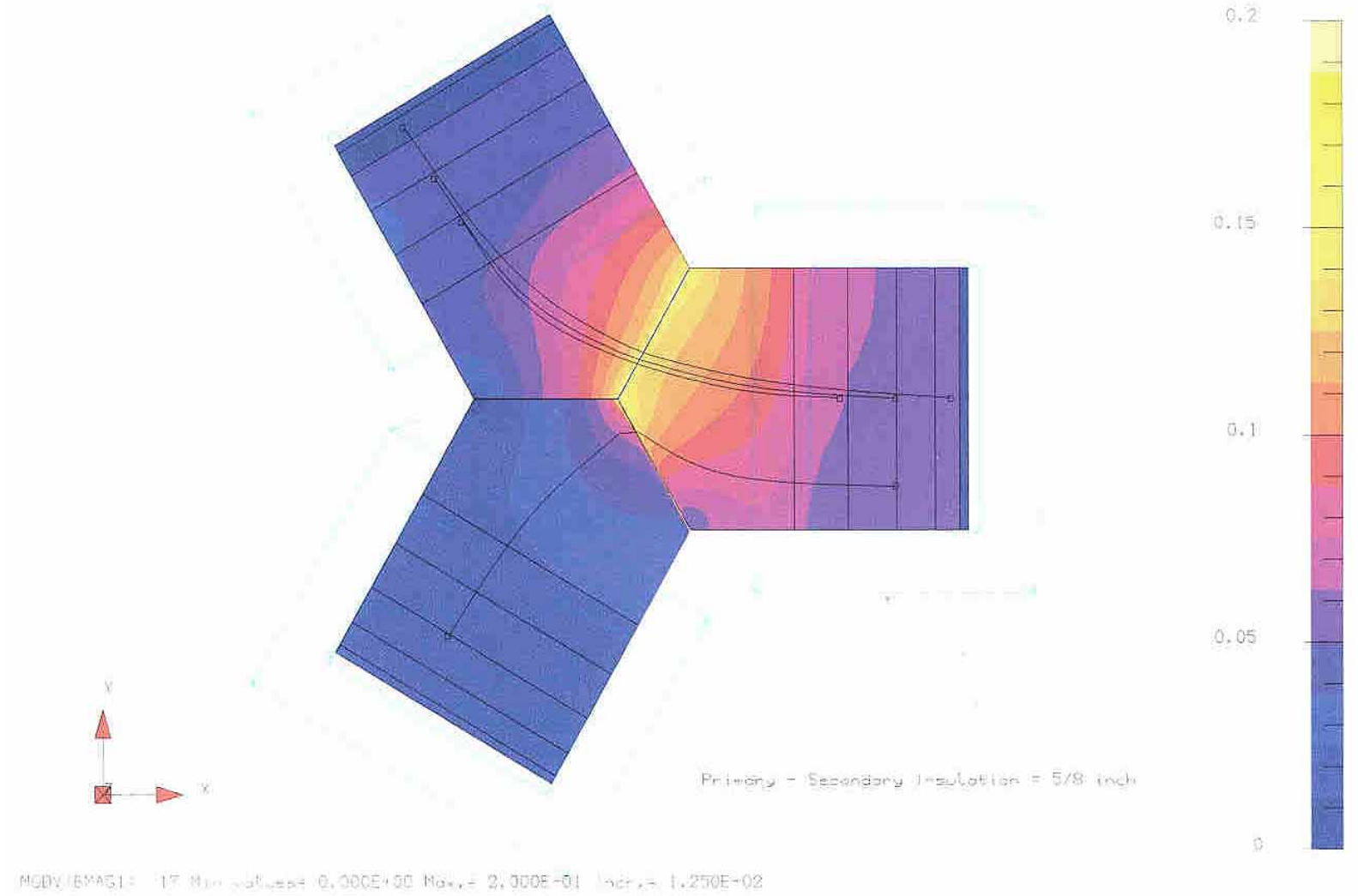
- Good Flux Balance
- Highest Performance
- 2 Gaps Per Winding Pair

DISADVANTAGES

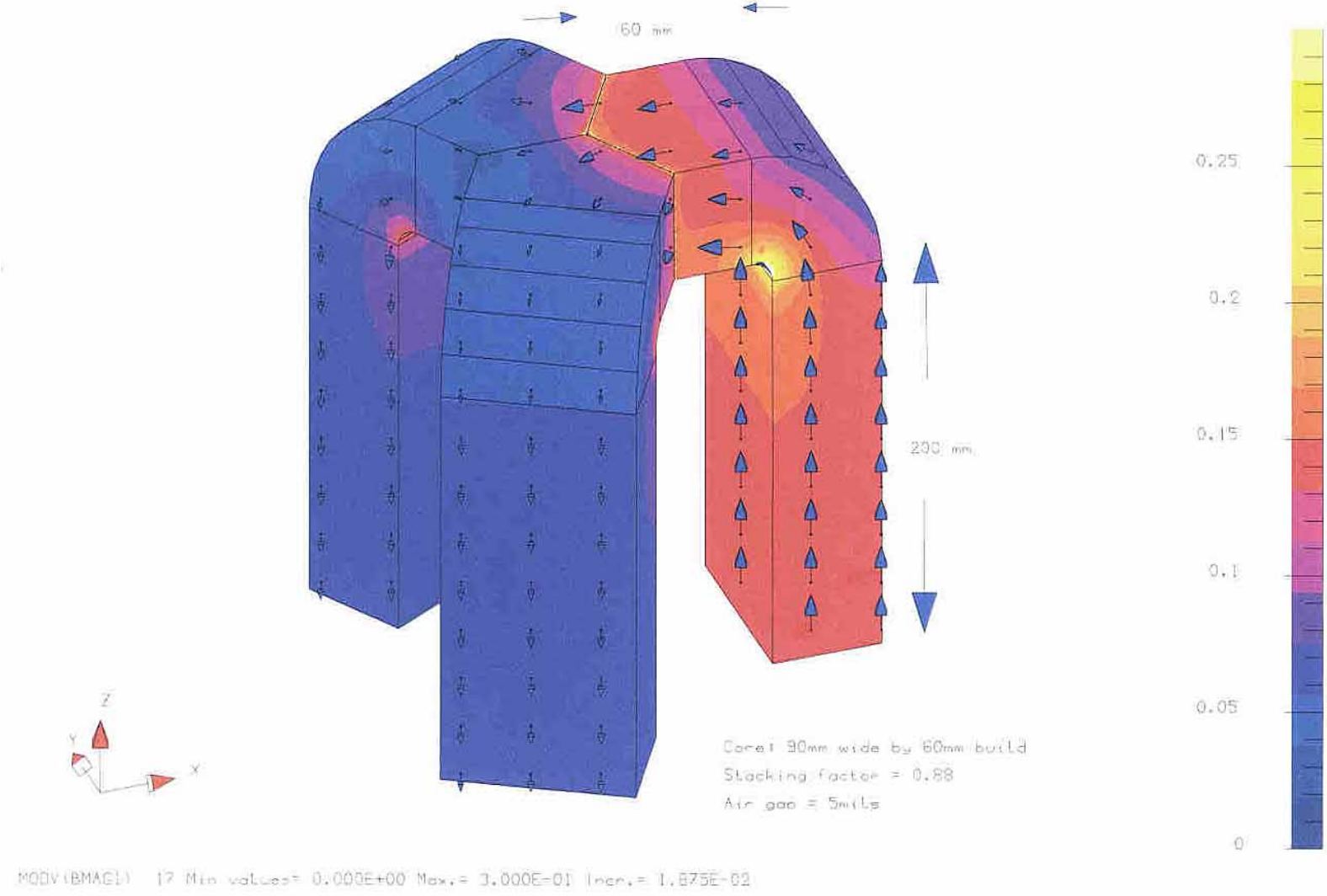
- Windings On Core
- Hard To Manufacture
- Sensitive To Tolerances
- Could Not Manufacture Previously



Flux Asymmetry Caused By Chamfer



Flux Concentration On Inner ID



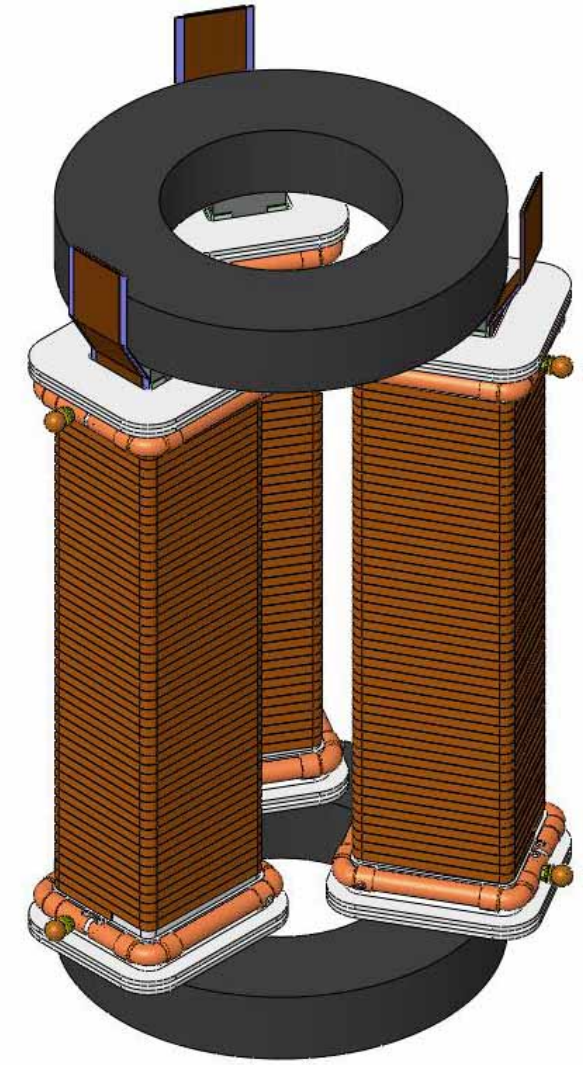
Ring Bar Transformer

ADVANTAGES

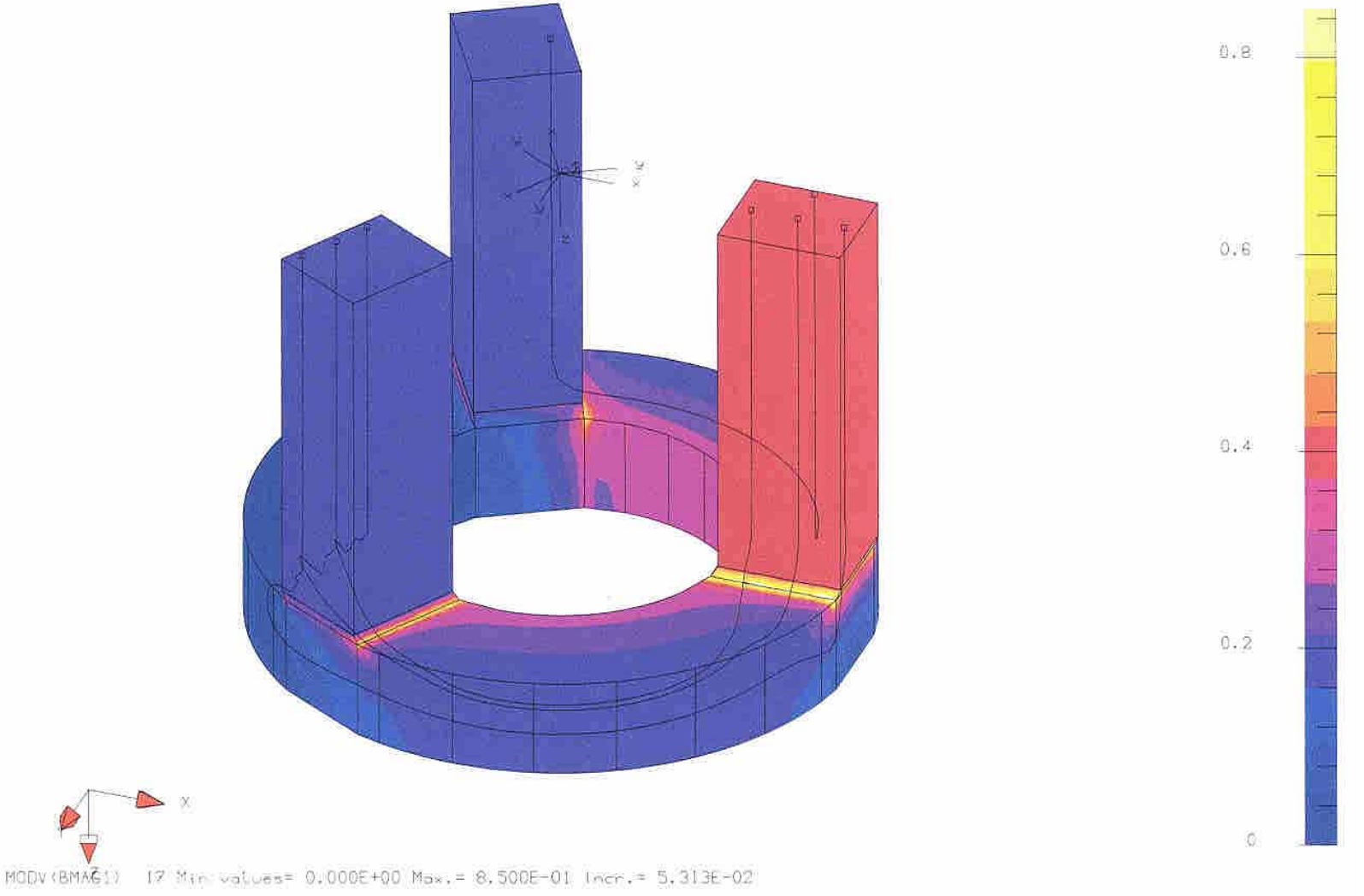
- Simple Topology
- Can Use Winding Bobbins

DISADVANTAGES

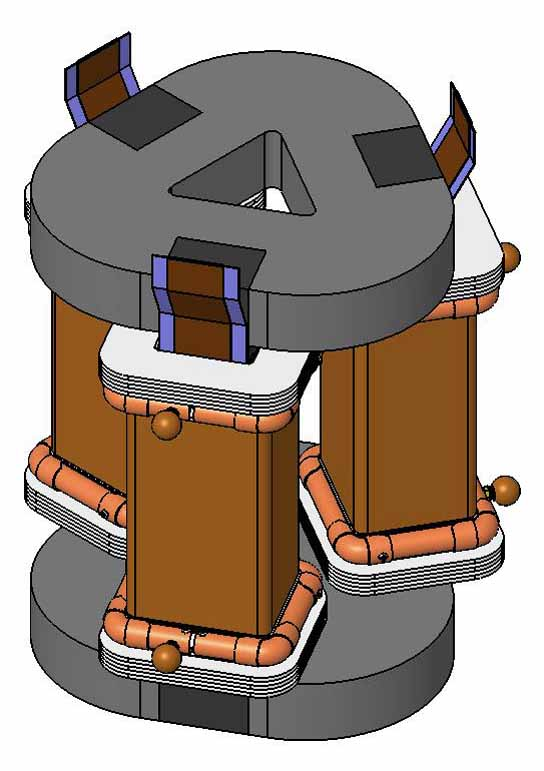
- Higher Reluctance Path
- 2X Core Gaps
- Mechanical Robustness (?)
- Secondary Tabs On Narrow Dimension



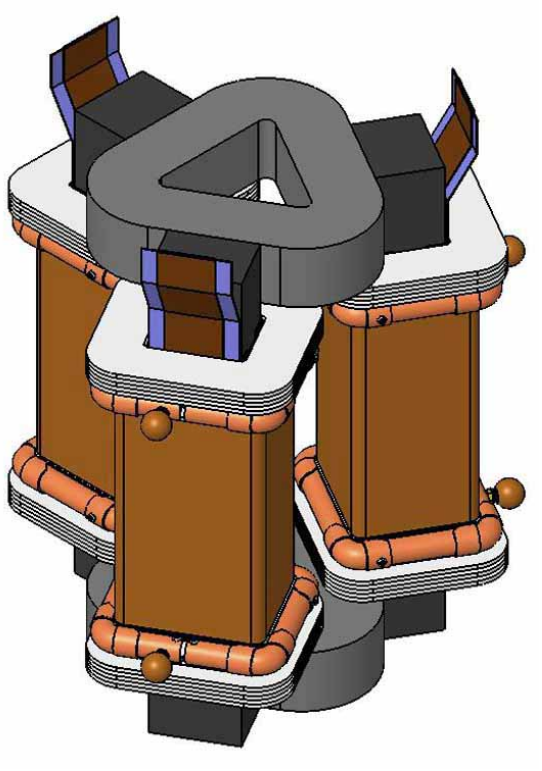
Some Flux Concentration At Interface



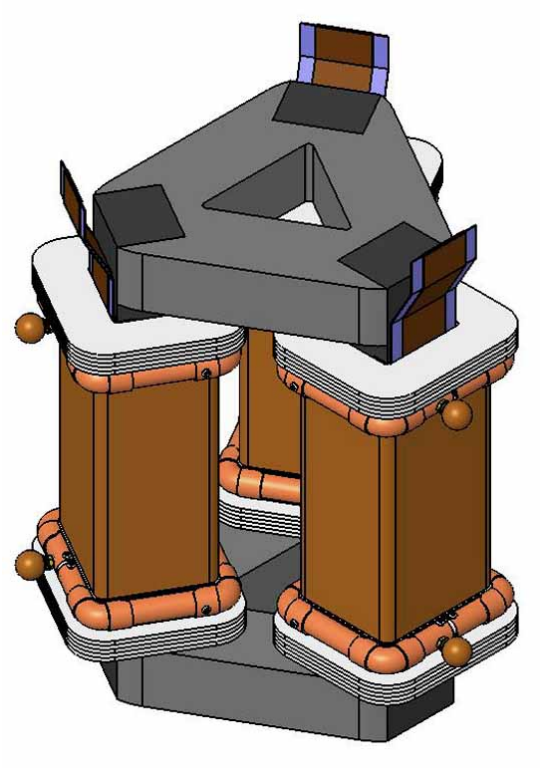
Triangular Bar Transformer Design Possibilities



OPTION 1



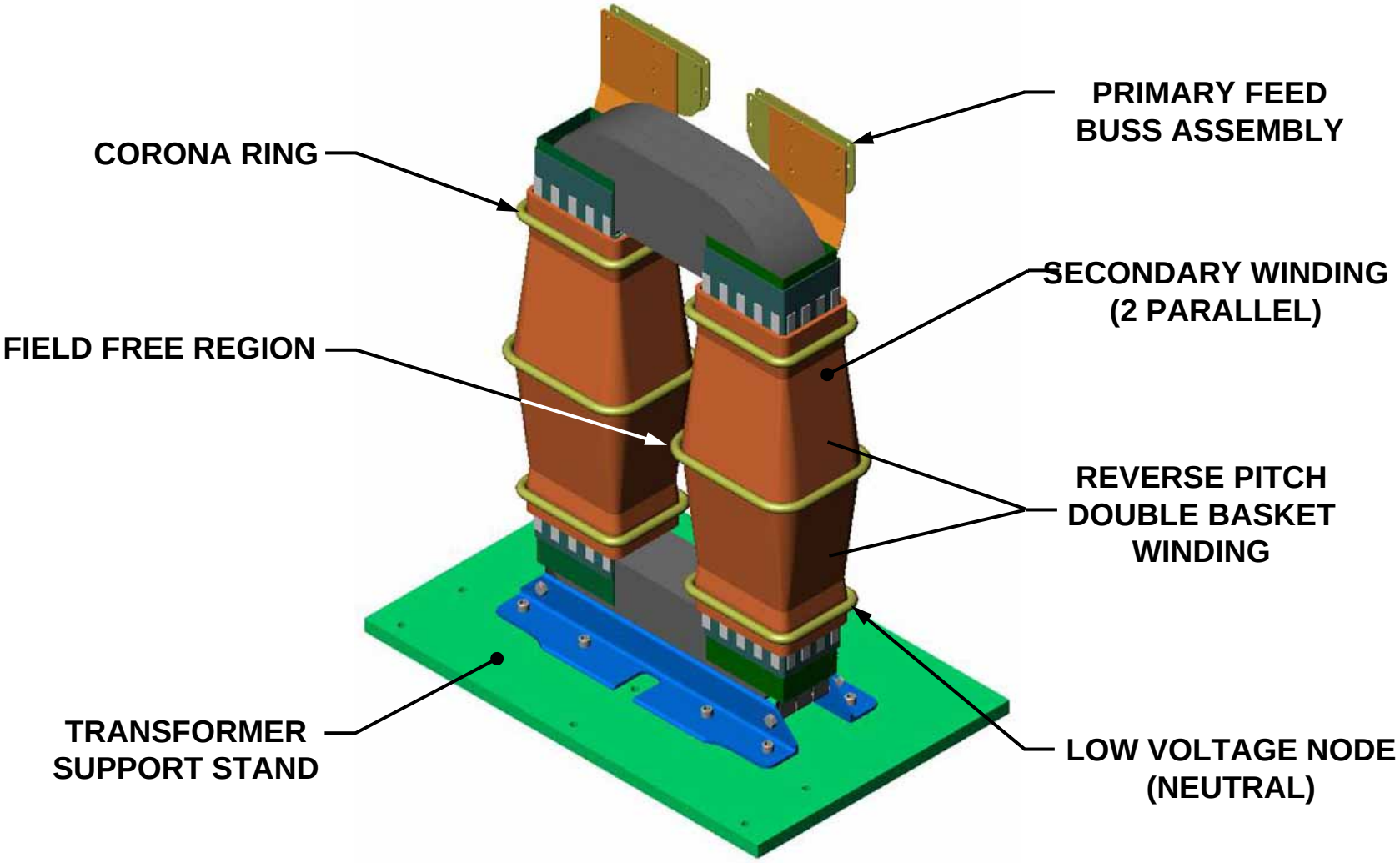
OPTION 2



OPTION 3

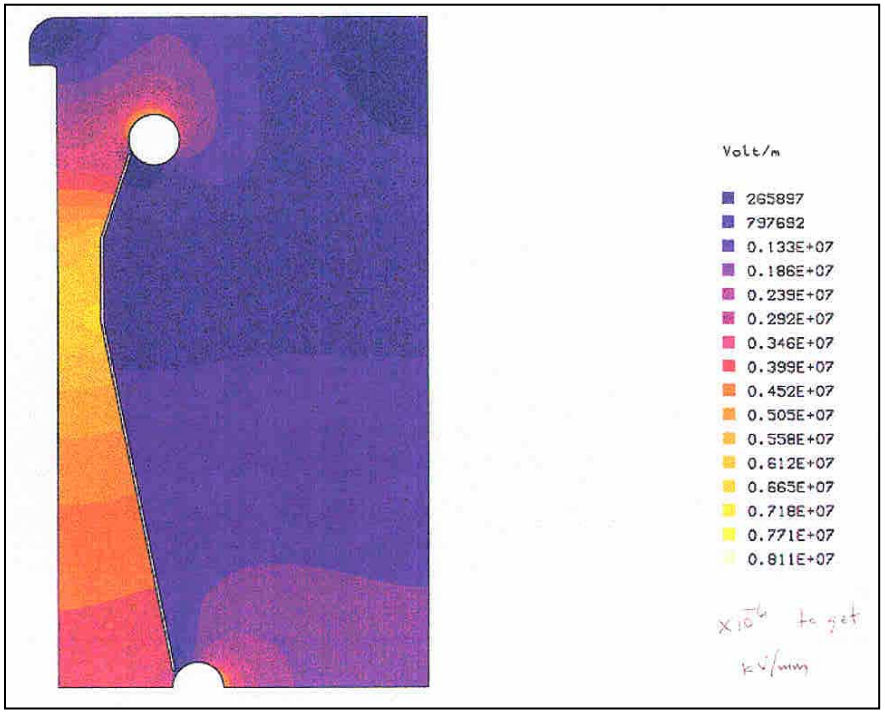
Flux Concentration At Corner And Interface

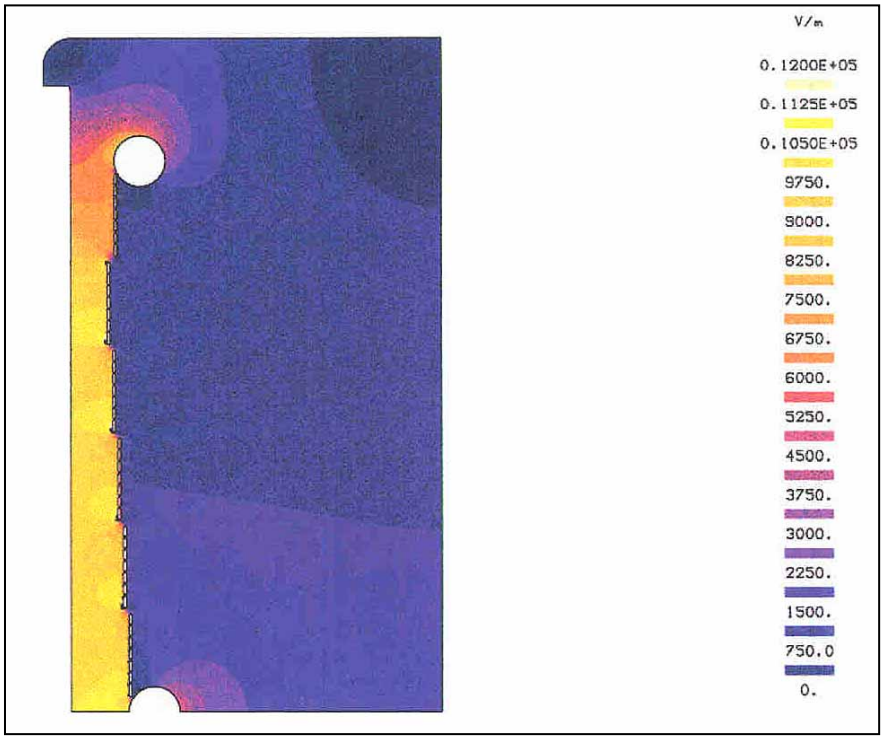
C-Core Designs Offer Higher Efficiency



Advanced Winding Topology Minimizes Field Stresses And Leakage Inductance

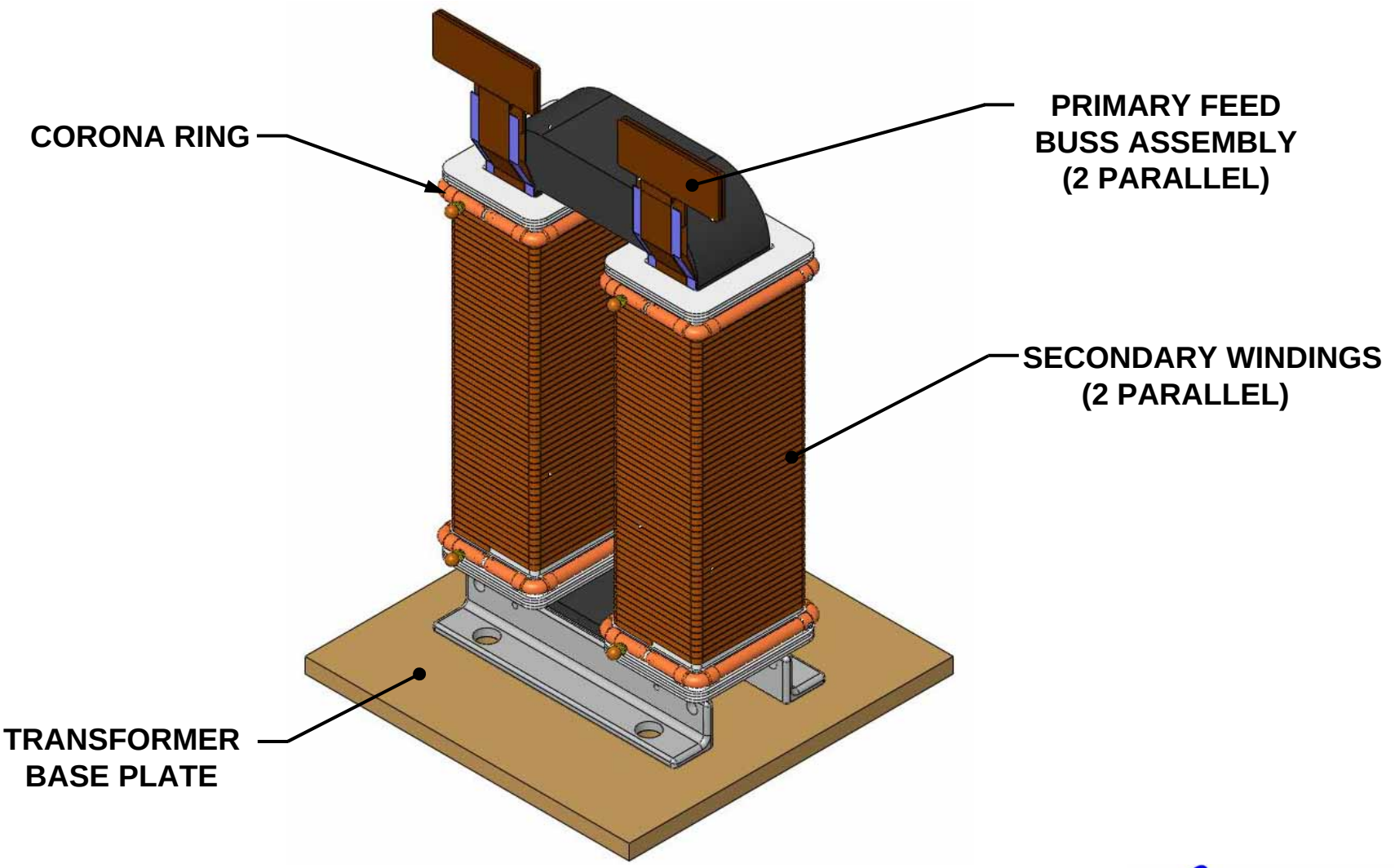
Winding Taper Improves Performance





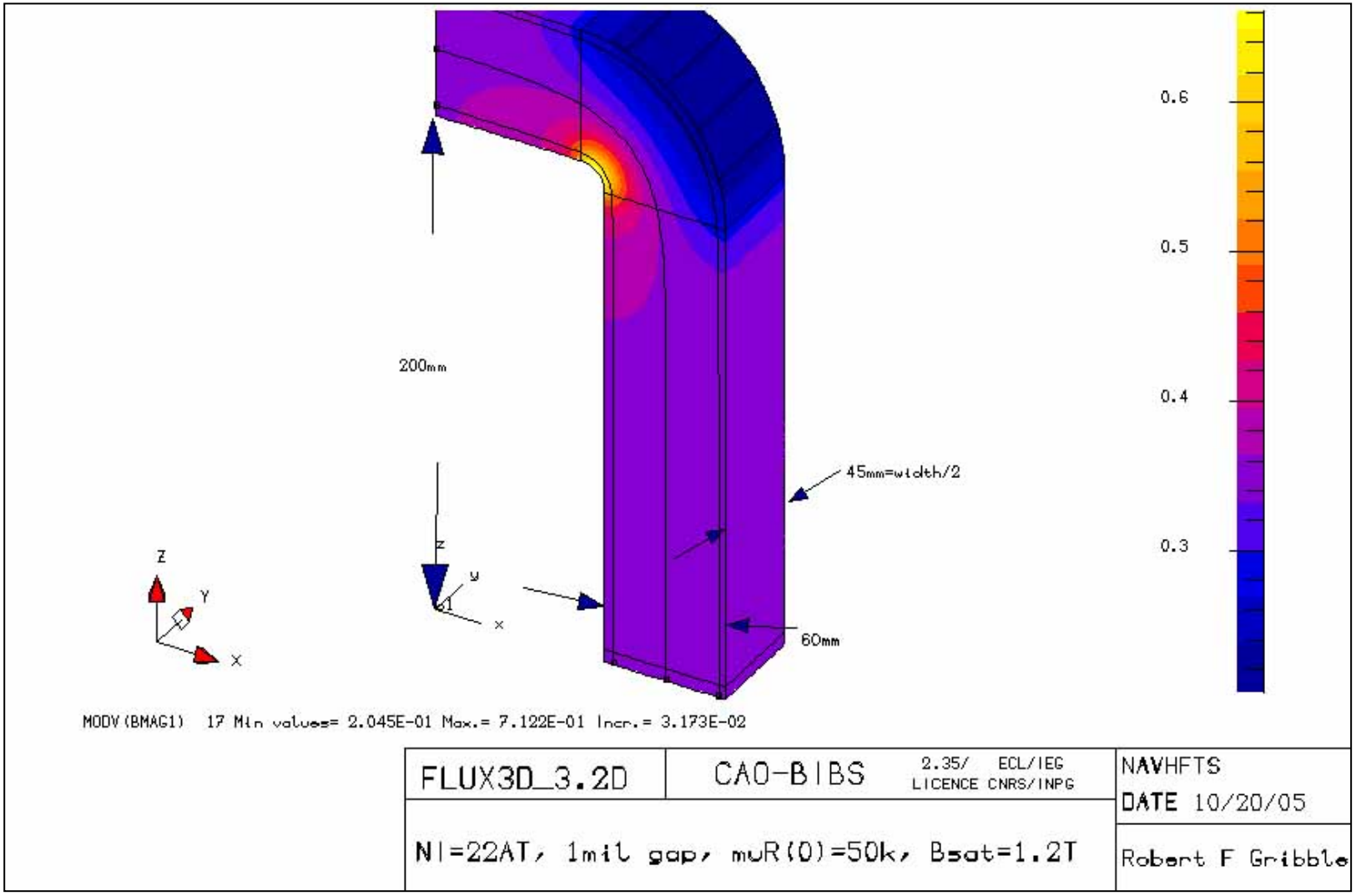
- Double Basket Design has Lower Field Stress
- Lower Leakage Inductance (than single layer solenoid with same field stress)
- Minimized End Effects
- Hard to Wind
- Reduced Copper Strength

A Simple C-Core Design



Use for Each Phase of Multiphase System

“C-Core” Flux Density

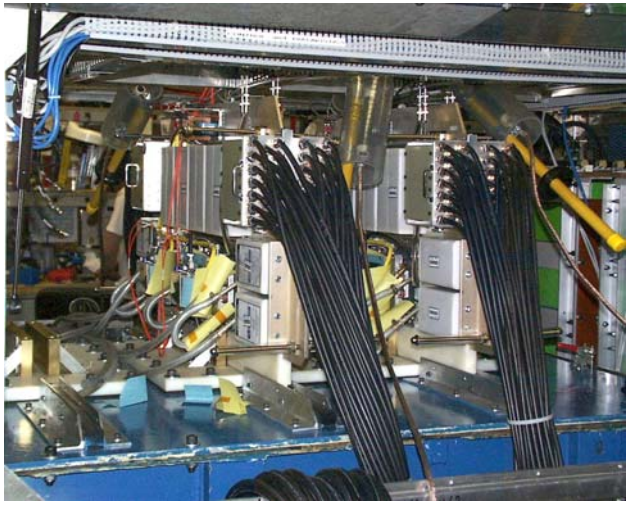


Transformer Conclusions

- C-core designs probably best for multiphase (more than 3) systems
  - Can drop single phase to continue operation
- Advanced core designs probably best for demanding requirements at mid-power levels using a 3 phase converter topologies
- Winding techniques are also important
  - Reduce leakage inductance
  - Reduce field stresses

What We Should Also Accomplish

20 KHz, 10 MW Polyphase Pulsed Converter



20 KHz IGBT Switching Assemblies

- We Can Reconfigure Los Alamos 10 MW, 20 KHz Pulse Converter To Evaluate Transformers
  - Appropriate Utilities In Facility For Full Power Testing
- We Can Use Facility To Test Critical Components And Performance
- Converter Can Be Upgraded To 2.7 MW CW (Now > 1 MW CW)
- Use Facility To Test Designs
  - Catalog Performances
- Facility Is Unique

Conclusion

Los Alamos Has Delivered Multi-Megawatt Class High Frequency Converter And Transformer Systems To Multiple Institutions. We look Forward To Teaming And Assisting The Further Development Of This And Related Technologies.

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