Electromagnetic Interaction Between the Insert and Outsert Coils of the 105 T Magnet System

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Motivation

This project is an improvement upon the 100 T magnet design with an upgraded duplex insert with two nested coils driven by two separate capacitor banks to create a pulsed non-destructive field of up to 105 T for ultra-high field research purposes.

This project uses finite element simulations implemented in COMSOL Multiphysics to address the following questions for the new duplex insert:

- What are the induced voltages on the insert and outsert when the insert is fired?
- What are the magnitudes of the induced currents in the metal reinforcement shells and their role in decoupling between the insert and outsert?
- What is the force distribution along the winding for each insert layer?

Design

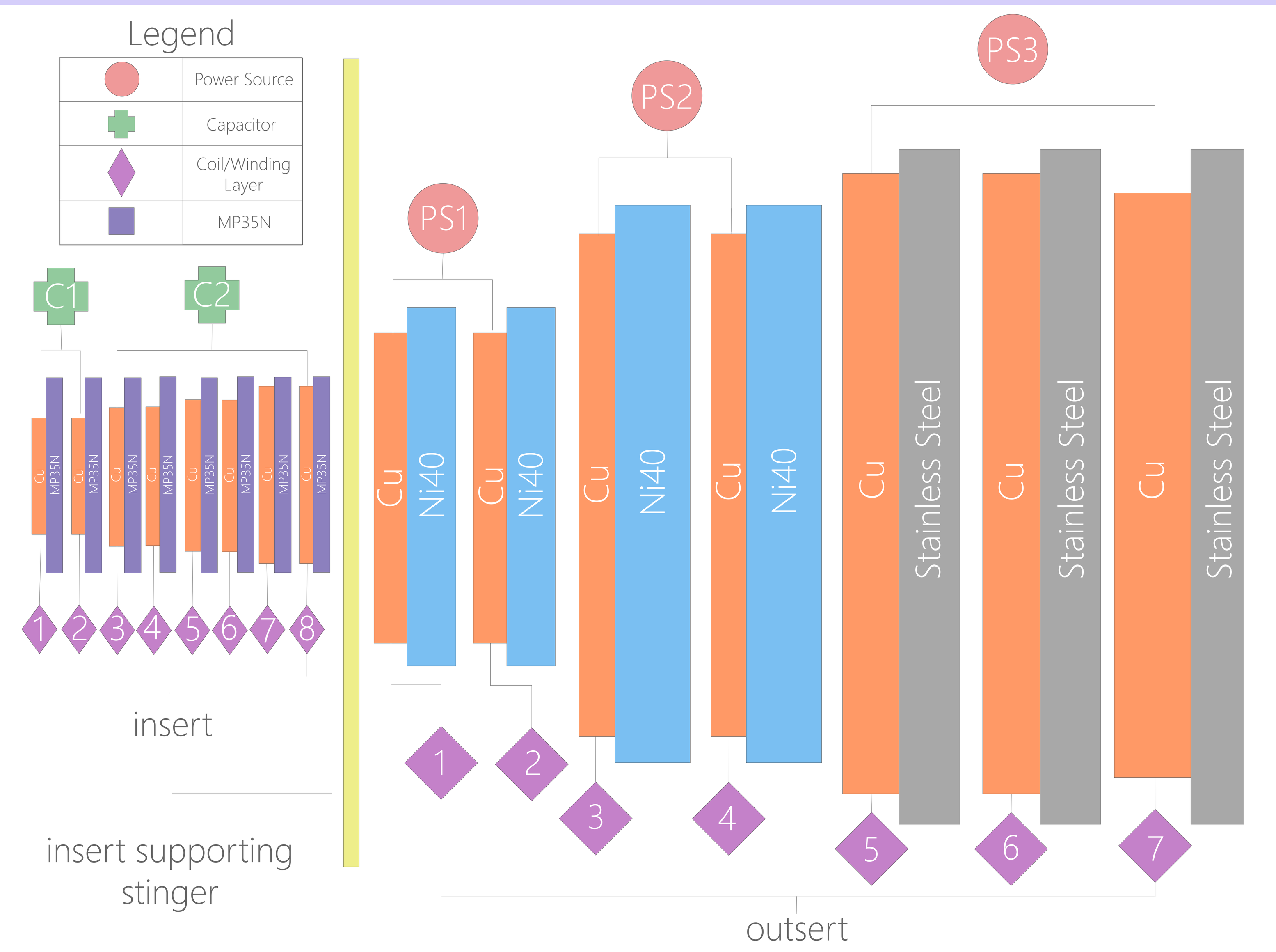
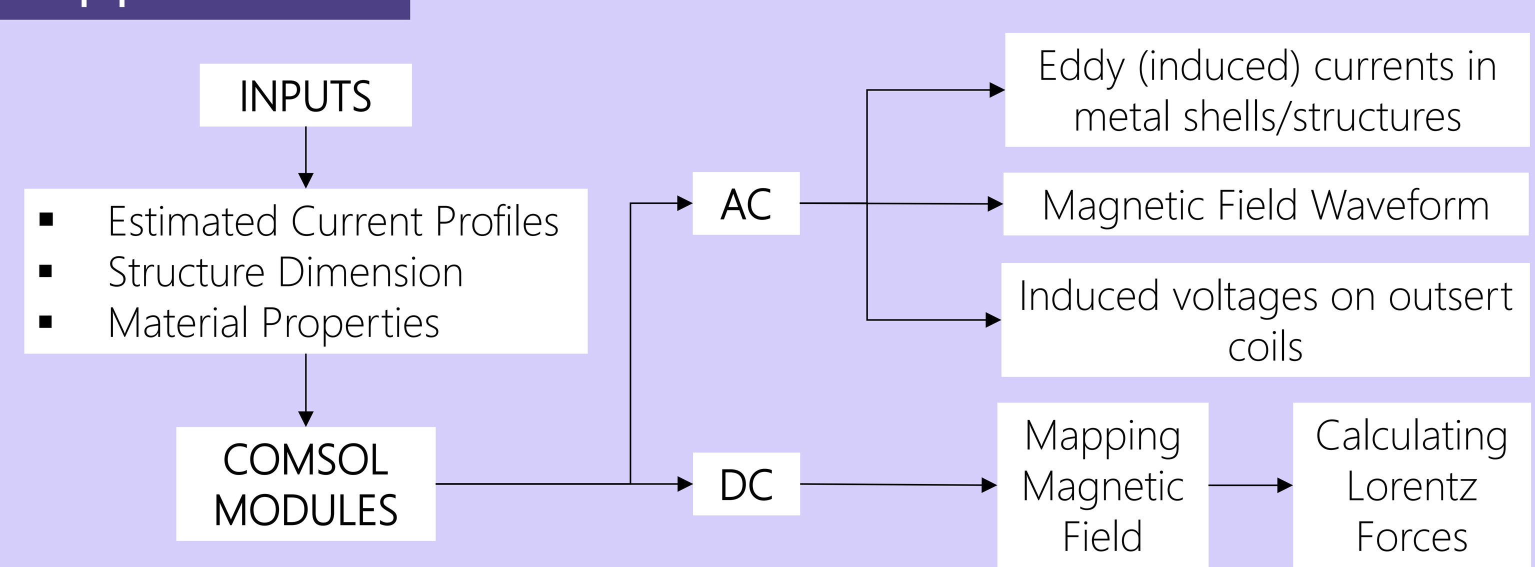


Figure 1. Not to scale. 2D representation of the 105 T magnet system with duplex insert.

The system is composed of the insert and outsert magnets. The duplex insert consists of 8 winding layers powered by two separate capacitors and its metal reinforcement shells are comprised of MP35N. The outsert consists of 7 winding layers and is powered by three separate power supplies. The first four coils are reinforced with Ni40 shells and the last three with stainless steel shells.

Approach



Duplex Insert: Magnetic Field Waveform

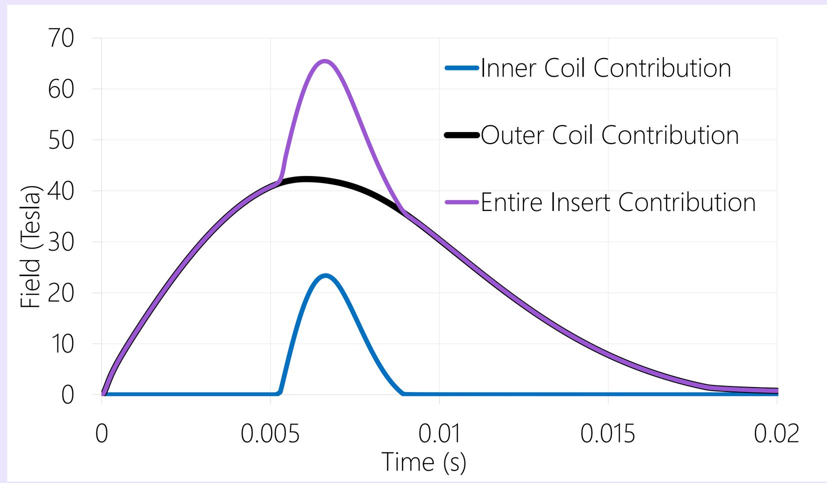


Figure 2. Waveforms for magnetic field contributions from the inner and outer sections of the duplex insert.

- Insert magnet provides 65 T field in 40 T background field of the outsert to create the total field of 105 T.
- Pulse length of the insert field is approximately 18 ms.
- Maximum field of 65.5 T occurs at 6.6 ms.

Induced Voltages and Eddy Currents When 65T Insert Fired

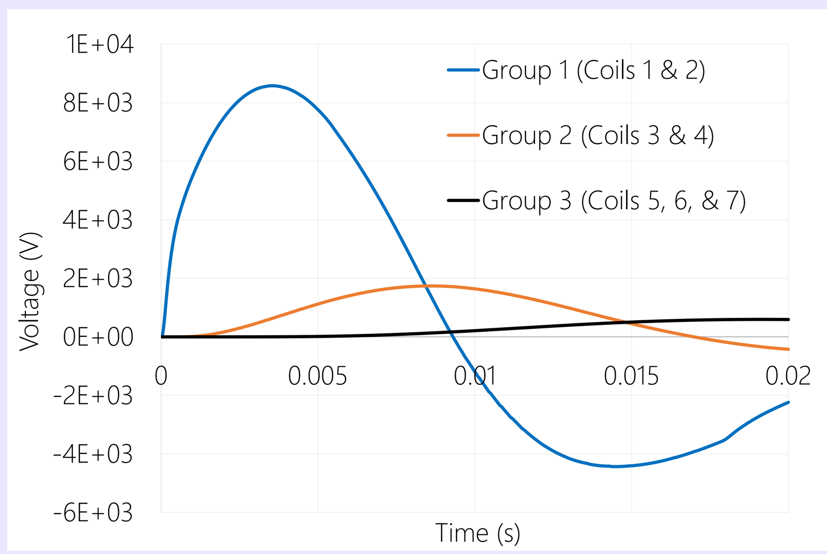


Figure 3. Waveforms of induced voltages on outsert coils with metal shells when only the insert is fired.

- Induced voltage is quite significant, up to 8 kV in Coil Group 1.
- Induced voltages in Groups 2 and 3 are much lower.
- Outer coils have more metal shells inside and eddy currents in those shells reduce the coupling (induced voltages).

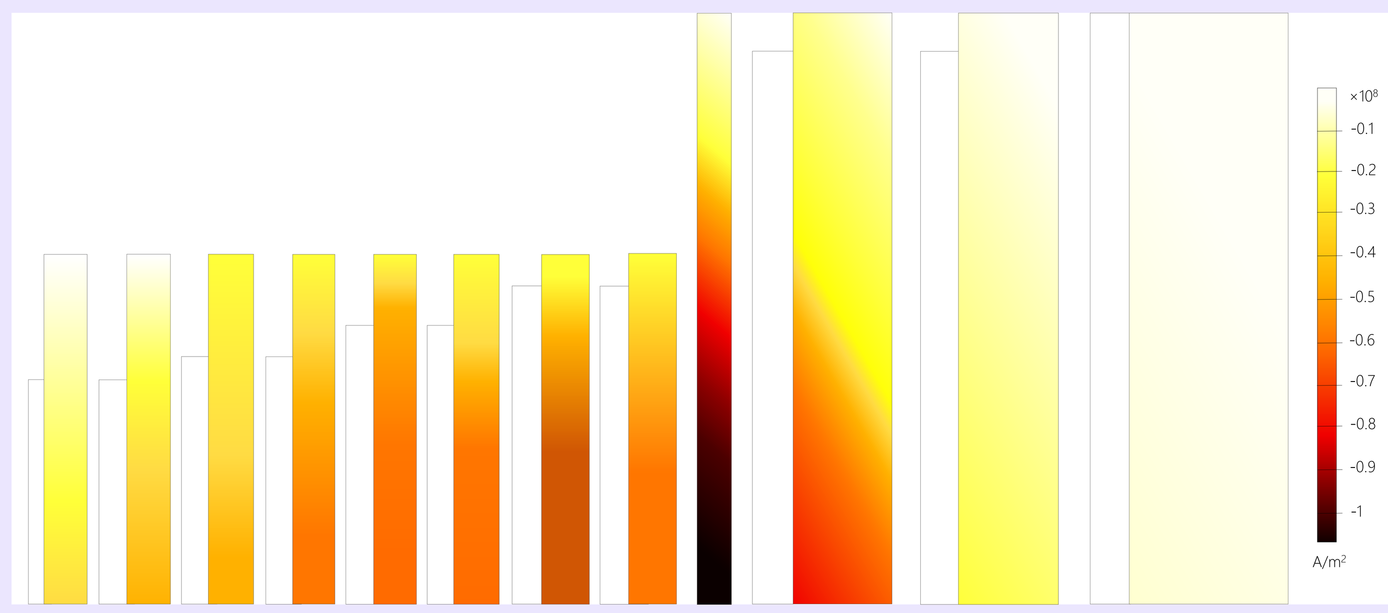


Figure 4. Induced current (A/m²) in metal shells at 5 ms after insert fired.

- High eddy current in shells.
- Inner shells have higher eddy currents.
- Current of greatest magnitude, - 1×10^{8} A/m², occurs in stinger.
- Very low induced current beyond outsert shell 2.

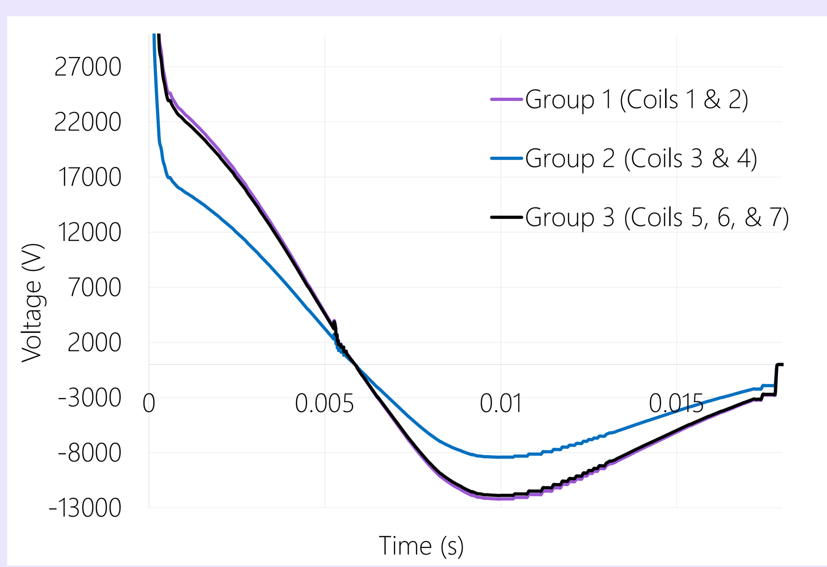


Figure 5. Induced voltages on outsert coils without metal shells when only the insert is fired.

- Shells significantly reduce the coupling between insert and outsert magnets.
- Without the shells the induced voltage is much greater in all three coil groups.
- Max of 90,000 V.

Lorentz Force on Insert Winding (105 T)

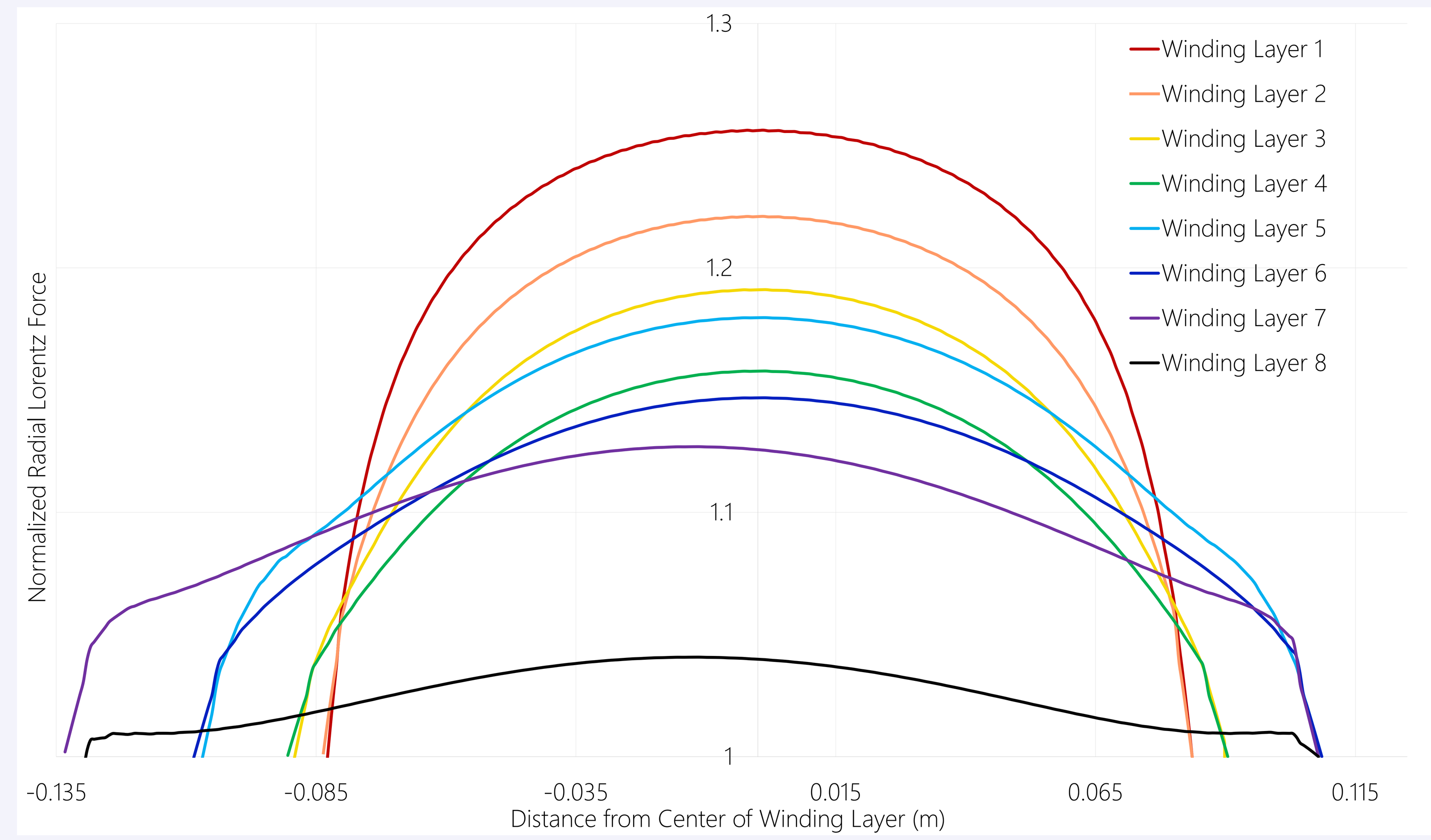


Figure 6. Radial Lorentz force component on different layers of the insert magnets normalized to the force at the ends of each layer .

- Radial Lorentz force at the winding center is much higher than at the ends. Those differences vary greatly with winding layers—that difference is greatest in layer 1 and lowest in layer 8.
- This study provides important guidance for the use of fiber/cloth reinforcements; a certain amount of zylon fiber (high hoop strength) can be replaced by zylon cloth (lower hoop strength but higher axial strength) near the coil ends to handle for the high axial force at the end (see Figure 7 below).

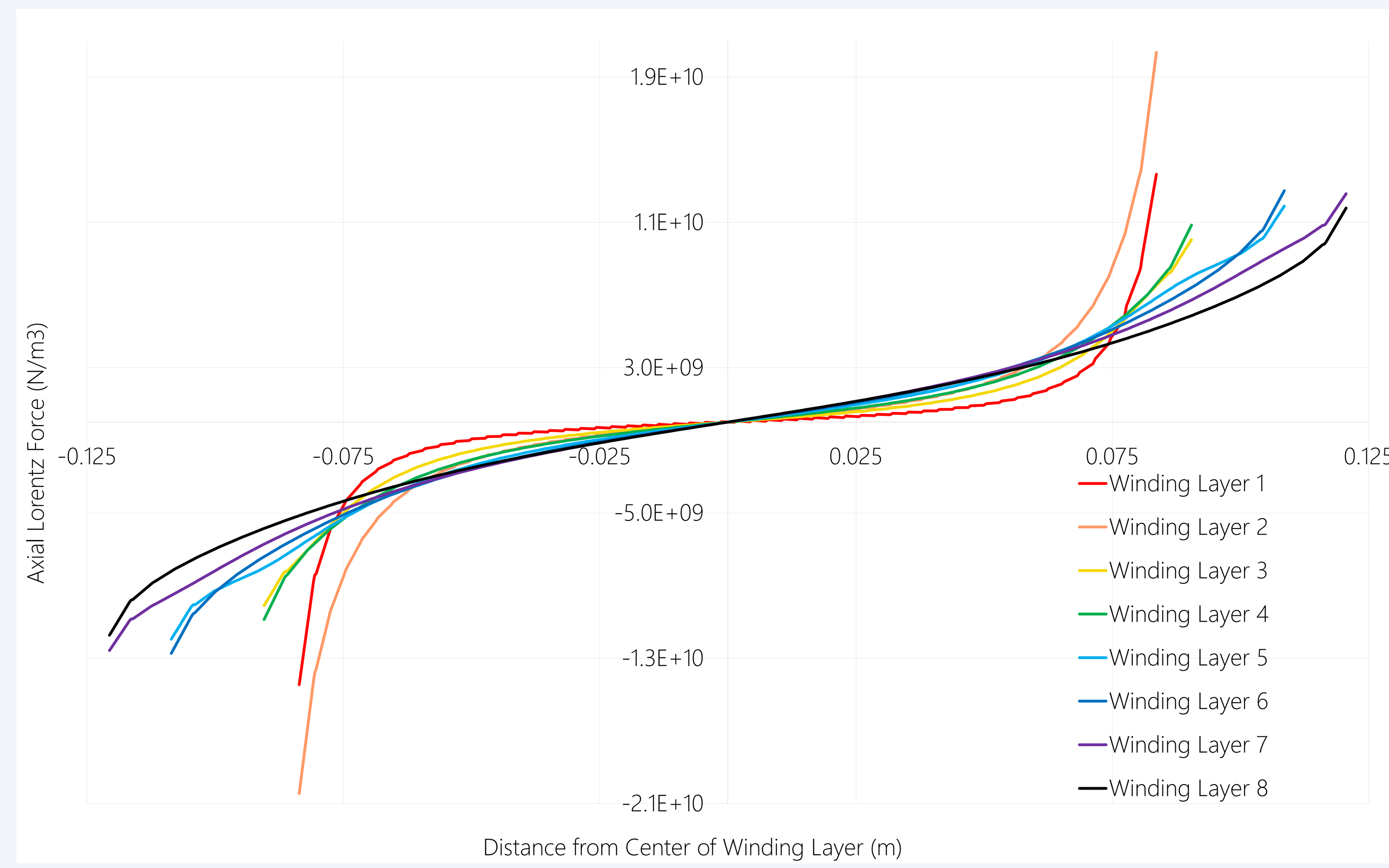


Figure 7. Axial Lorentz force component on insert coils. Data is scaled.

- Axial Lorentz force is high at the end of winding due to the radial field components and becomes zero at the winding center.

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