# Reducing Magnetic Field Ripples for 60T Long Pulsed Magnet

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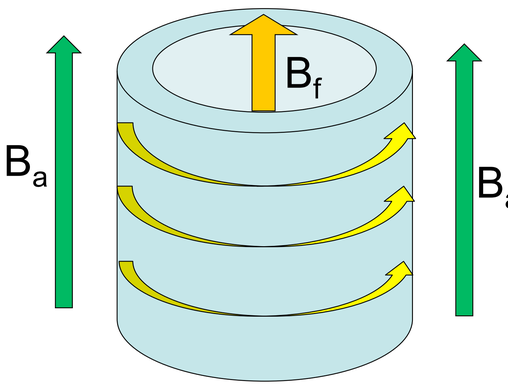
## Motivation

The 60 Tesla Long Pulsed magnet (60TLP) at Los Alamos is a unique system because it can provide a 60T pulsed magnetic field with 100ms flat top. However because the magnet is driven by a generator via rectifiers, magnetic field contain high-frequency ripples resulting in significant amount of noise for experiments. **COMSOL Multiphysics software was used to investigate the possibility of implementing a copper tube within the bore of the magnet to reduce the ripples by answers the following questions:**

**1.What is the suitable tube thickness and corresponding ripple reduction?**
**2.What are the temperature rise and Lorentz forces in the tubes?**
**3.What is thickness of Zylon reinforcement needed to support the tube?**

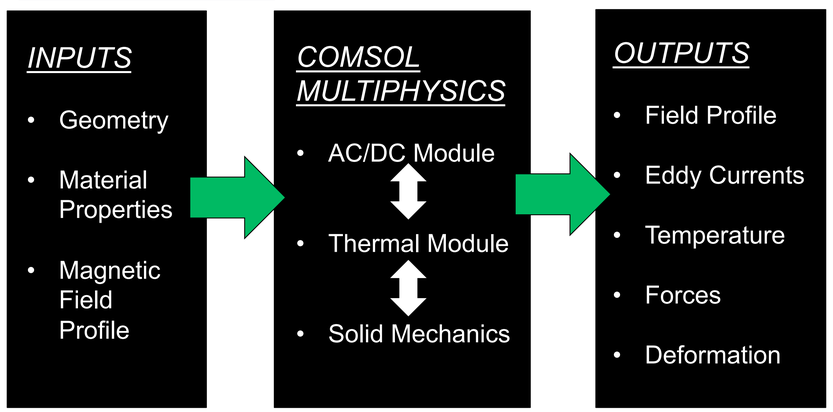
## Design




The copper tube (blue) is placed within the initial magnetic field $B_a$ (green). Because of high dB/dt of the ripples, we have eddy currents (yellow) circulating the tube. These currents in turn create a more stable magnetic field $B_f$ inside the tube (orange) which will be used for user experiments

*Figure 1. Not to scale. 3D representation of the copper tube within the bore of the 60TLP magnet*

## Approach




Temperature dependence of electrical conductivity and mechanical properties of materials is taken into account.

## Results

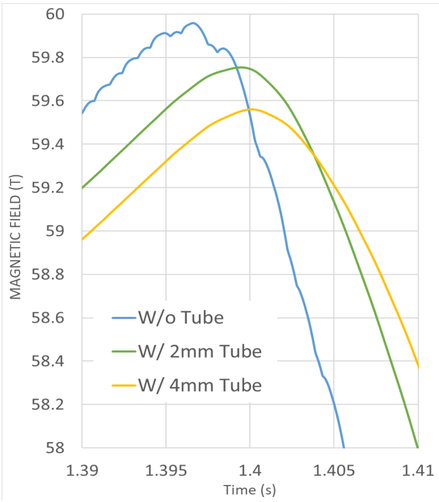



*Figure 2. The overall magnetic flux density vs time near the peak field.*

- The field profiles with a dampening Cu tube are significantly smoother.
  - Noise reductions in dB/dt:
    - 2mm tube : ~62%
    - 4mm tube : ~85%
- The magnetic field reduction is marginal:
  - 2mm tube : -0.2 Tesla.
  - 4mm tube : -0.4 Tesla.

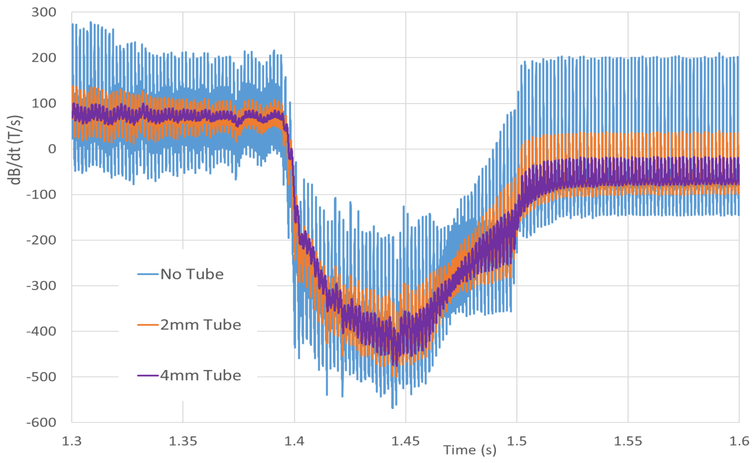



*Figure 3. dB/dt is plotted near the peak field for the initial condition w/o copper tube, compared to the cases with the 2mm and 4mm copper tubes.*

- The temperature rise is quite significant from 77 K:
  - 2mm Cu tube: to 168 K.
  - 4mm thick Cu tube : 160 K.
- As expected, the temperature rise is greater when the |dB/dt| is higher.
- This is important because the conductivity, elasticity, and tensile strength of copper are temperature dependent.

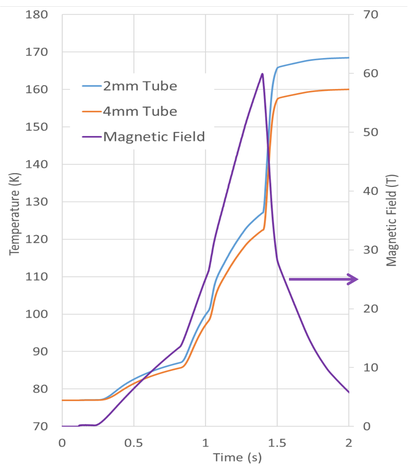



*Figure 4. Temperature rise in the copper tubes, during a 60 T pulse. Field profile is also plotted*

- The force density is nearly the same for the 2mm and 4mm Cu tubes.
- The force changes direction when dB/dt changes sign.
  - dB/dt >0 (field increasing), force is compressing the tube.
  - dB/dt <0 (field decreasing), force is outwards.
- With a maximum force density of 3.8e10 N/m^3, the tubes require Zylon fiber reinforcement.

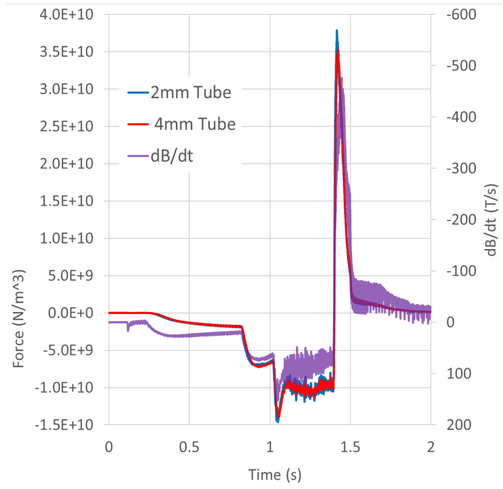



*Figure 5. Average force density in copper tubes vs time during a 60T pulse; dB/dt is also plotted*

- The thickness of Zylon fiber reinforcements are calculated to keep the strain within the Copper tube to less than 0.2%. Zylon is treated as a orthotropic material with very high Young modulus in hoop direction.
  - 2mm Cu tube requires 0.7mm thick Zylon fiber.
  - 4mm Cu tube requires 1.0mm thick Zylon fiber.

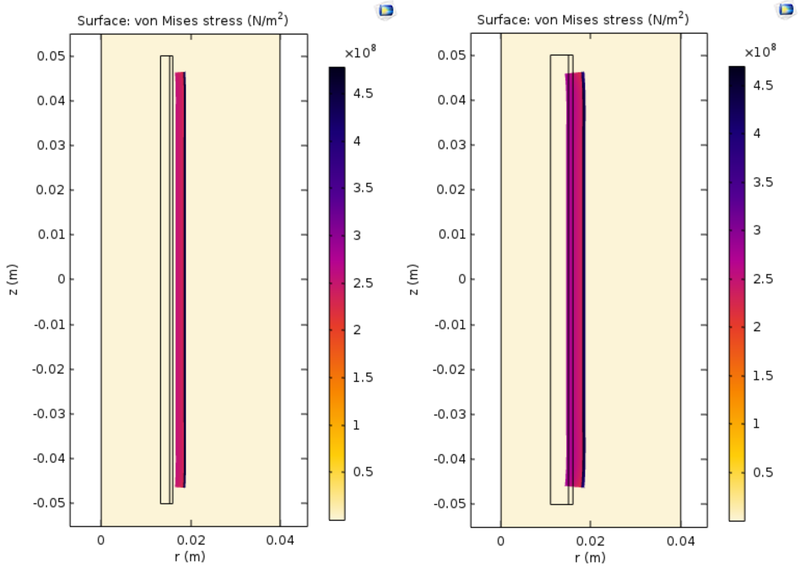



*Figure 6. 2D representations of the stresses on the 2mm and 4mm copper tubes, reinforced with Zylon, deformation shown with a 100X Magnification.*

- These plots demonstrate the deformation with 100X magnification. Since Cu tube operate in plastic regime, the deformation will become larger after each pulse and should be replaced after 1000 shots

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