Design, Construction and Operation of New Duplex Magnet at Pulsed Field Facility-NHMFL

James R. Michel, Doan N. Nguyen, Do T. Vo, and Jason D. Lucero

[1]Los Alamos National Laboratory, [2]National High Magnetic Field Laboratory

LA-UR

Abstract

The Pulsed Field Facility (PFF)- National High Magnetic Field Laboratory (NHMFL) in Los Alamos, New Mexico has developed and operated a several types of ultra-high field pulsed magnets, including 100 T Multi-shot, 60 T Long Pulse, and an array of small 65 T magnets for users. Separately powering (nested) coils allows to both reduce the driving voltages and have a further degree of control over the pulse duration and therefore the current carrying capacity in conductor to maximize the produced magnetic fields. Duplex design with two nested coils powered separately by two capacitors has been used at several pulsed field centers to increase the generated magnetic field. In last year, PFF-NHMFL focus on developing such a magnet to generate maximum magnetic field up to 77 Tesla using existing 4 MJ capacitor bank. The magnet is expected to prove 75 tesla magnetic field during regular operation. A Metal Oxide Varistor (MOV) bank is used to protect the capacitor bank and its associated electrical components from the overvoltage in the case of a fault happening in the duplex magnet.

Magnet System

Figure 1. The magnet apparatus as installed under the user platform

The 304 stainless steel vessel is designed to contain debris in the case of a catastrophic failure of the magnet, thereby mitigating damage to surrounding equipment and devices. The containment vessel has openings at the bottom to vent a pressure pulse from a failure. The MOV bank is located next to the leads to allow the shortest possible electrical connection.

80 T Design

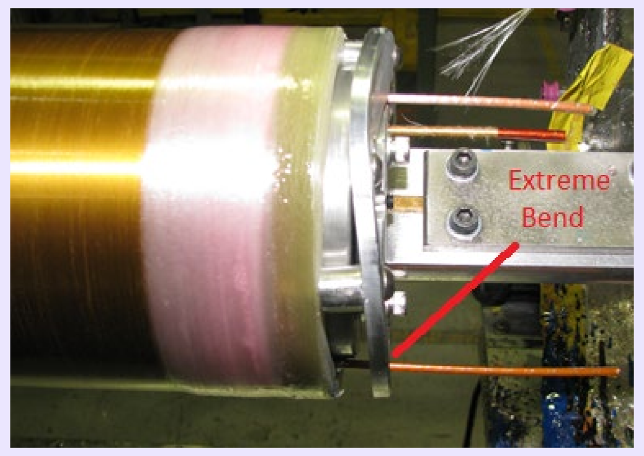

Figure 2. Layer # 5 tooling bend

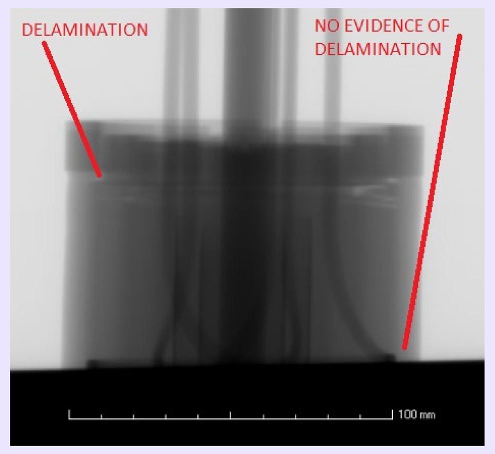

Figure 3. The X-ray image of the end spools of the duplex magnet

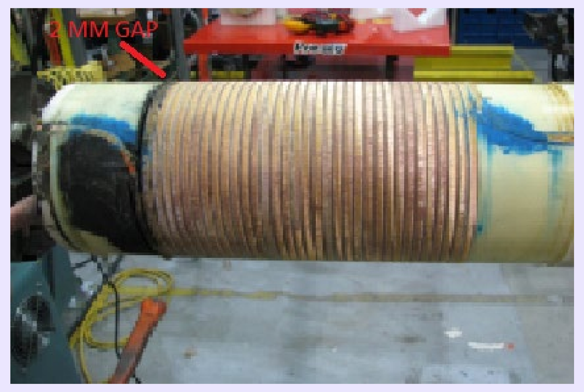

Figure 4. A gap was uncovered during the autopsy

The bending of the aluminum end-ring of the tooling indicates that the G-10 end-spool was pushed out due to high axial pressure caused by the pre-tensioned Zylon fiber banding. The x-ray indicated that the outer hub of the end spool had delaminated. The inner edge of the spool does not appear to have a gap. Upon autopsy, a 2MM gap was discovered of unsupported wire. The magnet failed in testing at 64 T.

77 T Design

The 77 T design incorporated a few slight design changes over the 80 T model. The operating voltage was reduced from 15 kV to 14 kV. The design uses more MP35N as reinforcement requiring less Zylon. This reduced the axial pressure on the tooling and improved the quality control of the fabrication process.

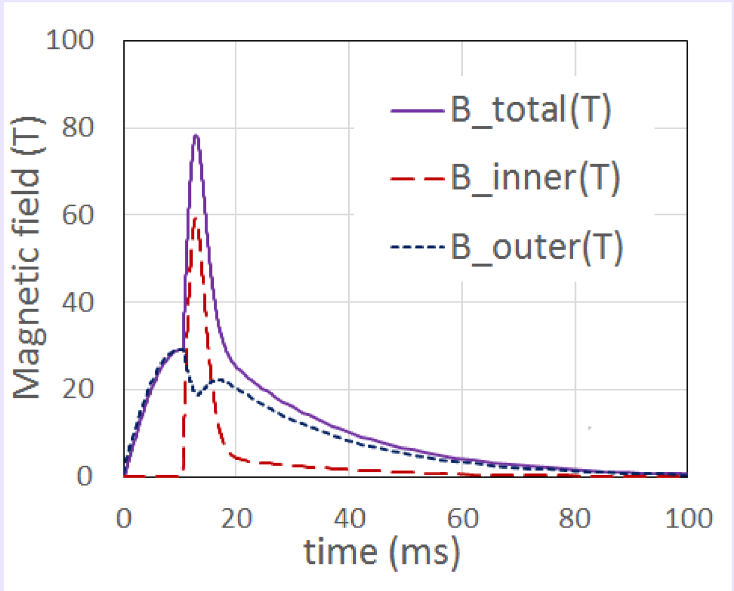

Figure 5. The waveform for the magnetic field

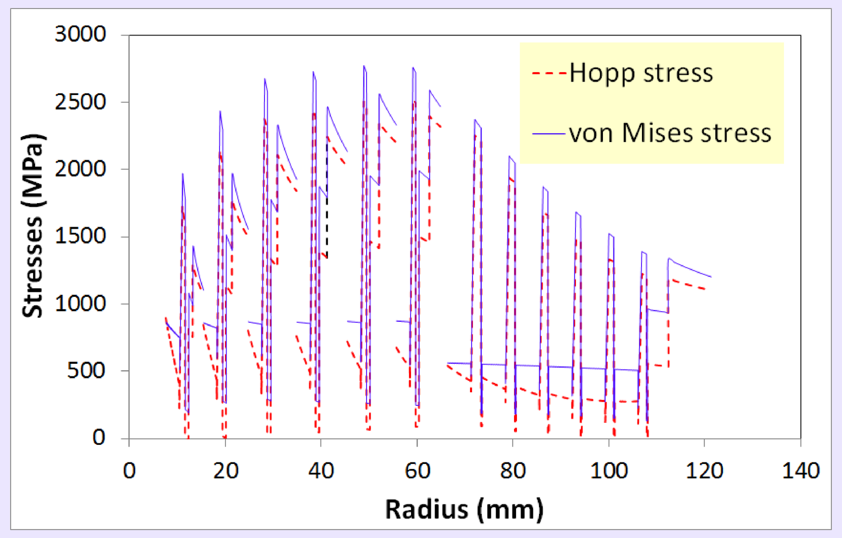

Figure 6. Hoop and von Mises stress

The 77 T duplex inner coil has a multi-helix design. It consists of 6 layers of CuNb with a cross section of 3 X 5.8 MM. The outer coil consist of 6 layers of 5.2 X 7.2 MM continuously wound AL60 wire. The outer coil produces 20 T using a 3 MJ sub-bank. The inner coil produces 58 T using a 1 MJ sub-bank. The maximum field of 75 T is provided to the user with a total circuit energy of 2.9 MJ. The highest von Mises stress of 2.7 GPa happens at the zylon reinforcement layer of layer 5. The highest stress on the conductor reaches 870 MPa, 0.73 of its UTS. The magnet was fabricated and successfully tested to 76.8 T and is ready to support users needs.

Eddy Current

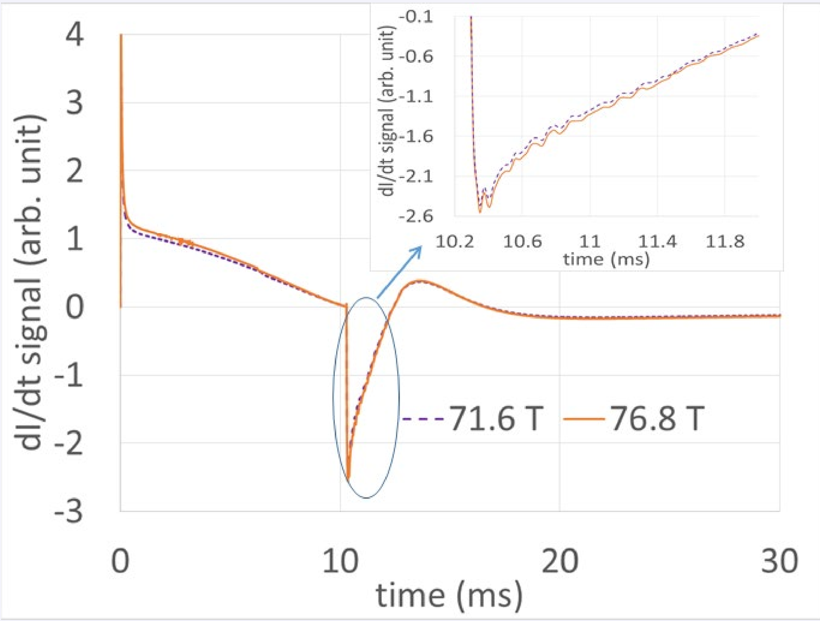

Figure 7. Idot signal for the outer coil at 71.6 T and 76.8 T.

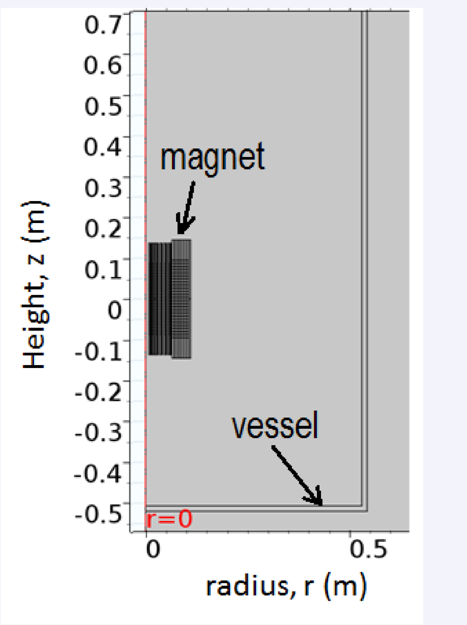

Figure 8. One half section of the model system in the vessel

The testing of the magnet has indicated that there is an interaction between the magnet and the containment vessel. The measurement of the time-derivatives of driving currents (Idot signals) and magnetic field (Bdot signal) indicates a considerable vibration when the inner coil is fired. The vibration is seen at 20 T and is repeatable with a larger amplitude at higher magnetic fields. It is suspected that the high dB/dt of the magnet may generate a high eddy current in the metal vessel which apply an electromagnetic force on the magnet and causes it to vibrate.

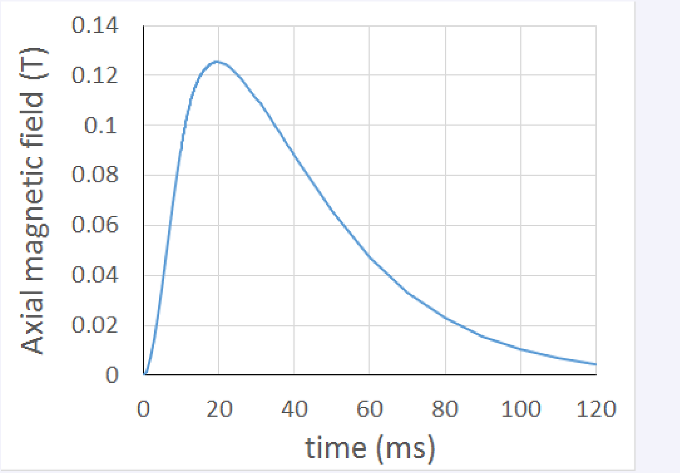

Figure 9. Axial magnetic field

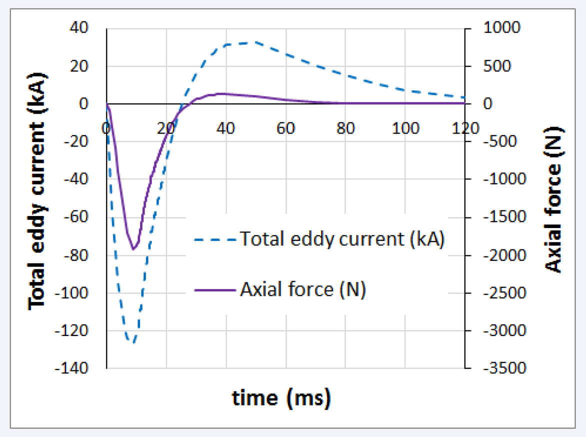

Figure 10. Eddy Current

Finite modeling was employed to analyze the electromagnetic interaction between the magnet and vessel. The model used a time dependent solver to calculate the eddy current and electromagnetic force acting on the vessel during the entire 78 T pulse. The shape of the magnetic field waveform is very different from that of the field inside the bore of the magnet. The total eddy current up to 127 kA is circulated in the vessel. This causes a magnetic force of 1800 N acting vertically on the magnet. The force gradually increase from zero and reach it peak of 1800 N at around 9 ms, right before the inner coil is fired. However, the oscillation in Idot and Bdot signals are only observed right after the inner coil is fired and that oscillation is damped when the inner coil reaches its peak field and the force of the vessel acting on the magnet is still reasonably high. Thus, the force acting on the magnet from the eddy current in the vessel may be not the primary reason causing the oscillations in the Idot and Bdot signals. Further investigation and testing will be required to understand the cause of the oscillation noise so that a quiet magnet can be provided to support users.