Stress and Strain Sensitivity Study of 1.5T Conduction Cooled MgB_2 Magnet Design.

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Target Audience – MR system development and applications.

Introduction – Magnetic Resonance Imaging (MRI) background magnets are generally made of low temperature superconductors that are immersed in liquid helium(LHe) to operate at 4.2K for persistent current (without constant power source) mode operation. Ever increasing LHe price has pushed researchers to design background magnets that could operate in conduction cooling mode. Magnesium diboride (MgB_2), a high temperature superconductor with a critical temperature of 39K can be used for MRI magnet design that are conduction cooled and would operate at a higher temperature compared to LHe. Some work has been done on designing MgB2 magnet for MRI application in past[1]. Previous work from the group has shown feasibility of designing a 1.5T whole body magnet using MgB_2.[2] However, a detail design for field strength of 1.5T or more including the mechanical aspect of magnet is yet to be presented. One of the major design challenges for high field MRI superconducting magnet is to keep the mechanical strain below the allowable safety limit of superconducting wire to protect the magnet from degradation and quench (magnet operating in resistive mode). As part of the manufacturing process of magnet coils, the wire needs to go through severe loading and unloading conditions resulting in cumulative stresses and strains in the wire bundles. The strain generated in the process affects the critical current of the superconducting wire[3].Moreover, excessive strain could reduce the peak critical current value significantly and initiate quench on the magnet. This problem is more acute in MgB_2 design due to its higher strain sensitivity compare to NbTi, a conventional choice for low temperature superconducting magnet design. Present study look into the challenges of stress and strain sensitivity of a 1.5 T MgB_2 whole body superconducting magnet during manufacturing process of prestressing, cooling and energizing of the magnet.

Methods – Optimized electromagnetic design of the 1.5T MgB_2 magnet[1] has eight primary coils and two shield coils as shown in quarter axisymmetric analysis in Figure 1. The shield coils which are of bigger radius faces the maximum stress during magnetic charging. Hence, investigation is restricted only to the shield coils. The coil has 28 layers of superconducting wire with an Aluminum mandrel of thickness of 2mm. The MgB_2 wire HyT30M[3] with properties shown in Table 1 is considered for the design. The winding process is modeled in commercially available software package ANSYS APDL using the birth and death of elements.[4,5] Subsequently, cool down is modeled by applying 298K to10K uniform temperature load and magnetic charging is modeled using 'EMAG' module by applying design current density on the conductors. Required properties of wire is read from P Kováč et al.[3] and thermal expansion coefficients (TEC) are calculated according to rule of mixture.

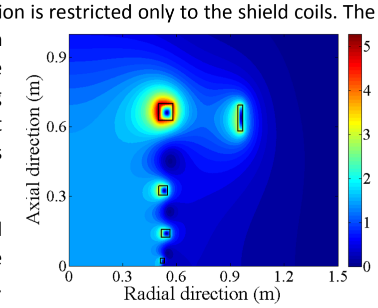

Figure 1: Magnetic field

Results – Figure 2 and 3 shows the hoop stress and Von Mises strain developed at each stage of the process for the shield coils. Each layer of coil is wounded with applied pretension of 66MPa. After the winding of 28 layers, 150MPa compressive hoop stress is developed in the mandrel whereas 66MPa tensile hoop stress develops at the outermost layer of the coil. During cool down to 10K operating temperature, stress in mandrel drops near zero. During the magnetic charging, the magnetic stress adds up and stresses peaks to 135MPa at the outermost layer. The equivalent Von Mises strain corresponding to this stress is 0.26% which is within a reasonable limit.

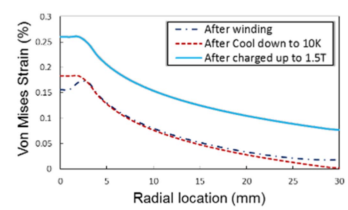

Figure 2: Hoop Stress

Discussion – During winding, a newly added layer exerts pressure on the previous layers. This generates, compressive hoop stress on the inner layers while the stresses stays tensile at the outer layers. After cool down to operating temperature, the mismatch between the thermal expansion coefficients introduces a sharp change in stresses in between mandrel and wire interface. Once the magnet is charged up, tensile hoop stress is observed in both the mandrel and outer coil layers but compressive hoop stress is still observed at the first few layers.

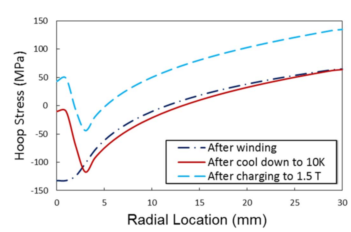

Figure 3: Von Mises strain

Conclusion – For a 1.5 T design using MgB_2 wire, the stress and strains are modeled numerically considering HyT30M wire. The hoop stress and Von Mises strains are plotted after winding, cooling and magnetic charging. The maximum cumulative strain develops after the magnetic charging. Results indicate a Von Mises strain of 0.26% which is well within the 0.4% limit. Hence, the study suggests that the for the proposed 1.5T conduction cooled magnet design, HyT30M wire is a safe choice.

	HyT30M	5083Al
E (GPa)	100	71.5
TEC (μm/m K)	9.95	14.5

Table 1: Material Properties

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