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EDDY CURRENT INDUSED STRESS ANALYSIS OF 1.5 T SUPERCONDUCTING MRI SYSTEM

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Abstract

A 1.5 T whole body clinical MRI magnet is under development at IUAC, New Delhi. The total stored magnetic energy of the magnet is 4.5 MJ that releases during a quench which adversely affects the magnet by raising its temperature and voltage. The quench in the magnet also induces eddy current in the electrically conductive parts of the cryostat. MRI magnet will be wound on the bobbin which will be made with aluminium alloy. MRI cryostat consists of liquid helium vessel (SS304L) thermal radiation shield (aluminium alloys) and vacuum jacket (SS 304L). During a quench, current decays down to zero within a short duration of time (<10 s), which causes change in the magnetic field and induces eddy current that generates the stress on various components of the cryostats. The OPERA-FEA software has been used to simulate quench induced eddy current and associated mechanical stresses on the various components. This paper briefly discusses the quench induced eddy current and associated mechanical stresses on various components of the cryostat.

Keywords: *MRI, Eddy Current.*

1. Introduction

The 1.5 T MRI has a multi coil solenoid superconducting magnet. The magnet will be protected with passive quench protection system with quench back heaters. The total stored magnetic energy of the magnet is 4.5 MJ that releases during the quench which adversely affects the magnet by raising its temperature and voltage. During quench event, passive protection scheme permits to distribute the stored magnetic energy within the magnet and allows raising its maximum hot spot temperature and peak voltage within the permissible limit [1]. The quench in the magnet also induces eddy current in the electrically conductive parts of the cryostat. When quench occurs, current decays down to zero within a short duration of time (<10 s). The rapid current decay causes change in the magnetic field and induces eddy current. The eddy current ultimately generates stress on various components of the cryostats due to Lorentz forces. Post quench stresses lead to deformation of the associated system [2-4]. This paper briefly discusses the effects of quench, induced eddy current and associated mechanical stresses on different components of the cryostat. The OPERA-FEA software has been used to simulate the quench, eddy current and stresses on the various components.

2. Post Quench Electromechanical Analysis

A passive quench protection philosophy has been adapted to protect the magnet using back to back diode based magnet subdivision along with a self-activated quench propagation circuit. This protection scheme allows magnet to spread the normal zone within the magnet [1]. Figure 1 shows the circuit diagram of passive quench protection scheme. The magnet has six primary coils (C1-C6) and two shield coils (C7-C8), which are subdivided in to two current carrying loops, as shown in Figure 1.

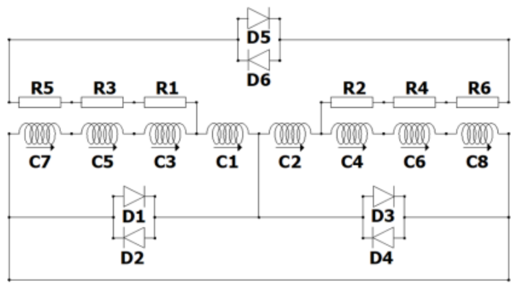

Figure 1. The quench protection scheme for the 1.5 T MRI magnet.

Quench back heaters (R1-R6) have been mounted directly on the top of the coils (C3-C8). Each of these coils has three surface heaters of 90Ω, located equiangular around the outer periphery of the coil. The magnet subdivision has been done with the back to back cold diodes (D1-D4). Another set of back to back diode (D5-D6) has been used for the propagation circuit. The end terminals of the propagation circuit are connected across the coil C1 and C2. The forward activation voltage of the diode is 10V. The magnet operates at persistent current mode.

The decaying current causes change in the magnetic flux which develops eddy current to the nearby electrically conductive system. The Lorentz force generates due to eddy current, which is responsible for the stress and deformation of the mechanical components. Generally, the maximum eddy current and stress generation happens at peak voltage time during quench [2-4].

3. Results and Discussion

The quench and associated eddy current have been simulated with OPERA FEA software for the 1.5 T MRI magnet. The quench has initiated by providing certain amount of heat flux in coil C6 (or C5), which is most prone to quench due to high field concentration on it. The temperature rise profile is shown in Figure 2. The maximum hot spot temperature increases up to 136 K in C3, whereas 110 K in C6. Coil C1 and C2 remain in superconducting stage during quench. The voltage rise and current decay profile are shown in Figure 3 and 4 respectively.

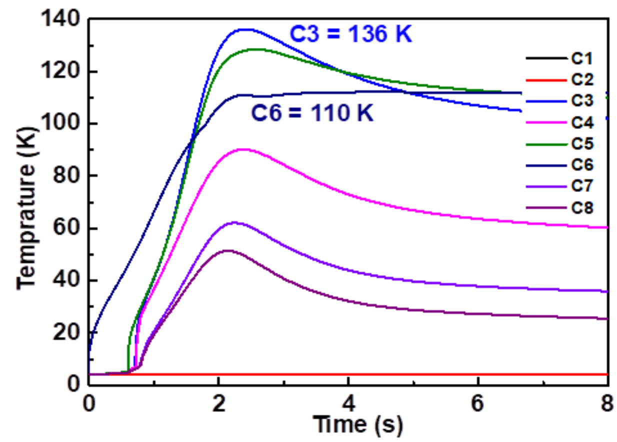

Figure 2. The temperature rise profile of magnet during quench.

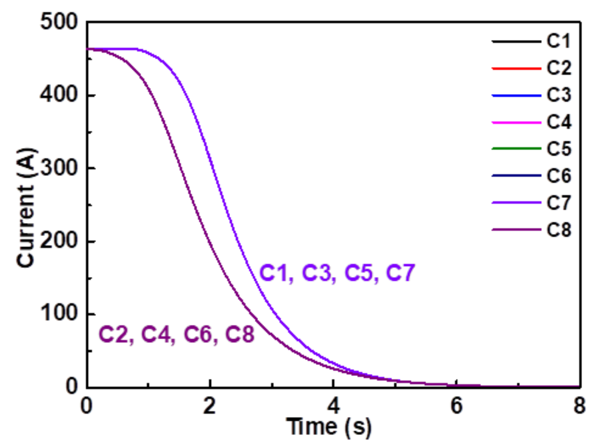

Figure 3. The current decay profile of magnet during quench.

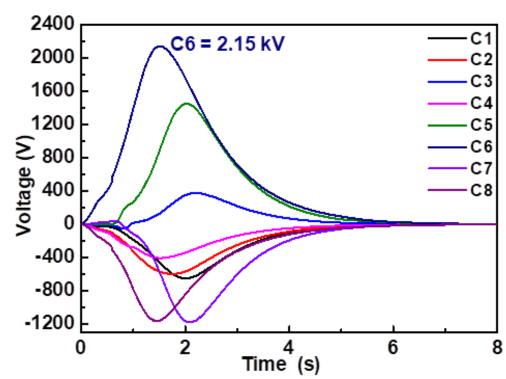

Figure 4. The voltage rise profile of magnet during quench.

The operating current, 460 A decays down to zero within 8s time. Current decays asymmetrically into two loops. The current decays faster, where quench is initiated (in coil C6) than the other loop. The maximum voltage rises up to 2.15 kV in coil C6.

Eddy current generates in magnet bobbin and thermal radiation shield during quench. The bobbin material has considered as AA 5083, whereas AA 1100 (bore) and AA 6061 (side plates) have been chosen for the shield for FEA simulation. The operating temperature of bobbin and thermal radiation shield are 4.2 K and 50 K respectively. Figure 5 and 6 show the eddy current generation with its directional vectors at maximum voltage time (1.5 s) during quench of bobbin and thermal radiation shield respectively.

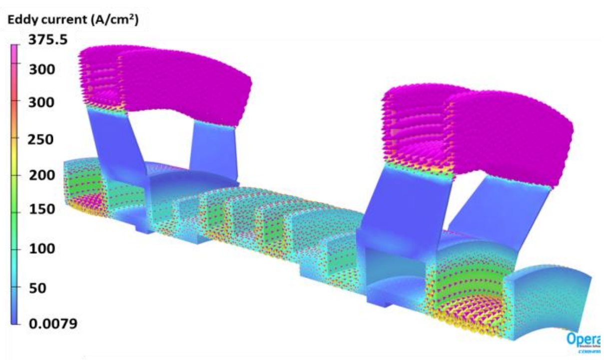

Figure 5. The eddy current generation in bobbin during quench.

The maximum eddy current density, 375.5 A/cm2 generates at the shield coil bobbin (C7 and C8) and the direction of it remains opposite to magnet current direction.

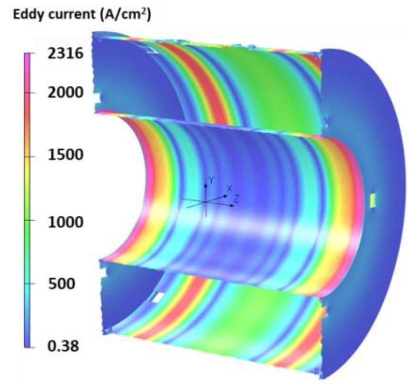

Figure 6. The eddy current generation in thermal radiation shield during quench.

The thermal radiation shield experienced maximum eddy current density 2316 A/cm2 near to the coil C5 and C6 in the inner bore and near to the shield coil region in the outer bore. The stress has been produced in bobbin and shield due to Lorentz forces and flux change. Figure 7 and 8 shows the stress profile of bobbin and shield respectively.

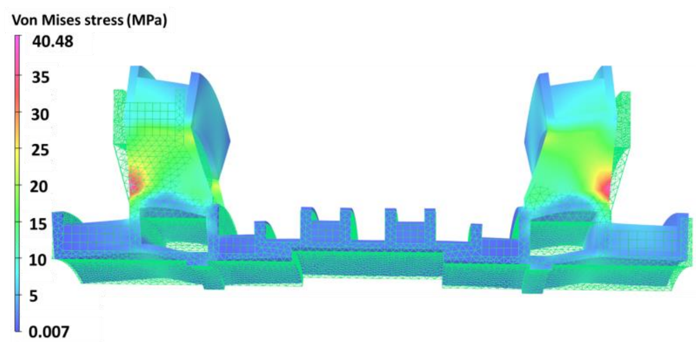

Figure 7. The Von Mises stress in the bobbin.

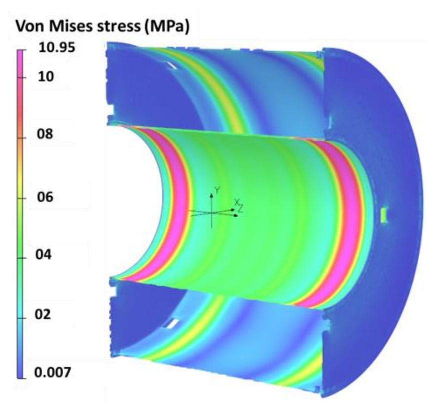

Figure 8. The Von Mises stress in the thermal radiation shield.

As shown in figure 7, the maximum von mises stress 40.48 MPa develops in the connecting ribs of the shield coil bobbin. In the thermal shield, maximum von mises stress 11 MPa produces at the inner bore near to the coil C5 and C6. The maximum von mises stresses are within the permissible limit of the proof stress of materials AA 5083 (proof stress- 215 MPa) and AA 1100 (proof stress- 35 MPa).

4. Conclusion

B The detailed transient quench analysis of the magnet and eddy-current analysis of the former and the thermal shield have been performed based on the FEA models. The Lorentz forces induced by eddy currents have been quantified for the mechanical analysis of the former and shield. The maximum working stresses are found to be under the allowable values. Therefore, the design can be implemented for the MRI system.

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