# Quench Propagation Study for Magnesium Diboride (MgB2) MRI Magnets

Charles Randall Poole[1], Tanvir Baig[1], Robert Deissler[1], Robert W. Brown[1], and Michael A Martens[1]
[1]*Department of Physics, Case Western Reserve University, Cleveland, Ohio, United States*

**TARGET AUDIENCE:** Audience interested in MR Engineering and MR Systems Design

**INTRODUCTION**: Magnetic Resonance Imaging (MRI) background magnets with low temperature superconducting Niobium Titanium (NbTi) wire operate in persistent current mode at 4.2K and use 2000 to 3000 liters of liquid Helium (LHe). With the projected increase in demand for LHe [1], it is worth considering conduction cooled MRI magnet designs that can operate with a few liters of LHe [2]. One such option is Magnesium diboride ($MgB_2$) wire, (with a critical temperature of 39 K), operated at 10 K or above [2]. The feasibility of conduction cooled $MgB_2$ design has been studied [3], and magnets with field strengths of 1.5 T or greater appear more feasible with the development of second generation MgB2 wire [2]. An important consideration is the magnet protection during a quench [4].Without intervention, the total stored magnet energy is converted into thermal energy [4,5], and if localized in a "hot spot", can lead to large temperature rises and the destruction of the magnet [4]. It is therefore vital that the quench protection be activated as early as possible to the prevent the temperature from rising above 200 K (an industrial safety limit) [4]. Compared to NbTi magnets, the minimum quench energy (MQE) needed to initiate a self-sustaining quench is an order of magnitude larger [3] and the thermal normal zone propagation (NZP) is significantly slower, which increases the challenge of quench protection for $MgB_2$ magnets [4,6]. This leads to the consideration of active (rather than passive) quench protection systems [4]. Previous work has used 1D and 2D models to calculate the MQE and NZP for $MgB_2$ tape [7]. In this study, we extend the investigation by using a 3D model and also consider the effect that the percentage of copper has on the MQE and NZP for a $MgB_2$ magnet operating at 10 K.

**METHODS:** A quench occurring in a small MRI coil is modeled in MATLAB (MathWorks) using the implicit Douglas-Gunn method to solve the governing heat equation [8]. The wire in the coil has a cross-sectional area of 2.16 $mm^2$ and contains $MgB_2$ filaments surrounded by a matrix with various fractions of copper, niobium, and Monel. In the direction along the length of the wire it is mainly the copper that contributes to the electrical resistivity and thermal conductivity whereas in the radial and axial directions, the thermal conductivity is determined by the wire's insulation (CTD-101k). The coil operates with a constant 256 A of current in the presence of a 3 T magnetic field resulting in a current sharing temperature of 18.3 K. Thermally, the axial and inner radial boundaries of the coil are fixed at a temperature of 10 K, while the outer radial boundary is insulated. To initiate a quench in this model, a small disturbance heater (2 cm x 0.18 cm) located on the center of the outermost layer is activated for 0.1 seconds. In the first set of simulations, the amount of $MgB_2$ in the wire remains fixed while the copper fraction is changed and then the minimum quench energy is determined by finding the smallest possible energy that initiates a self-sustaining quench. In a second set of simulations, a 3 W disturbance heater was on for 0.1 s on the same coil with varied copper percentages, and the temperature rise and resistive voltage was calculated. The NZP is determined by the distance the quench propagates over time.

**RESULTS:** Table 1 shows the calculated MQE and NZP for various copper fractions illustrating the fact that it takes more energy to initiate a quench when the percentage of copper is higher. The calculated MQE is comparable to the 300-400 mJ MQE shown in Ref 7. Figures 1a and 1b show the temperature rise and resistive voltage of the coil as a function of time during the initial stage of the quench which were all initiated with 300 mJ of energy. These calculations show that $MgB_2$ wires with an increased copper percentage have a larger MQE and a slower rise in temperature during a quench

| Copper Percentage | MQE (mJ) | NZP (cm/s) Azimuthal | NZP (cm/s) Axial | NZP (cm/s) Radial |
|---|---|---|---|---|
| 15% | 45 | 59 | 2.8 | 3.0 |
| 30% | 88 | 73 | 2.0 | 2.2 |
| 40% | 170 | 76 | 1.7 | 1.9 |
| 50% | 300 | 79 | 1.5 | 1.7 |

**Table 1. MQE and NZP versus copper percentages**

**CONCULUSION:** The rate of temperature rise and the development of the resistive voltage are important factors in the design of an active quench system. The threshold voltage used to detect and initiate the quench protection should be low enough for early quench protection, but large enough to prevent false quenches due to noise on the voltage taps [9]. The simulations show wire with higher concentrations of copper have a slower temperature rise but also a slower rise in the resistive voltage. However, the higher percentage copper is still advantageous since the improvement from a lower temperature rise offset the slower voltage rise. For instance, assuming a threshold voltage of 1 V, the coil with 15 % copper reaches a temperature of 65 K, whereas the coil with 50% copper reaches a temperature of only 37K when the restive voltage reaches 1 V. Thus the increased copper fraction would make it easier to detect a quench using a threshold voltage and actively protect the magnet.

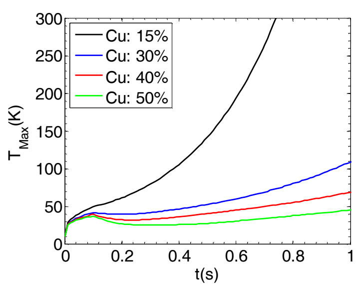


**Figure 1a**

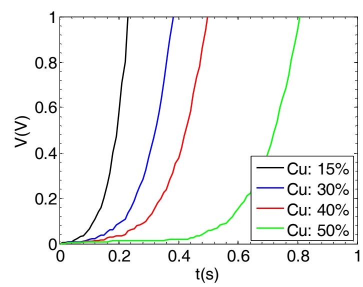


**Figure 1b**

**ACKNOWLEDGEMENT:** The authors would like to acknowledge the support of the Ohio Third Frontier and an NSF grant PFI:BIC 1318206 for this research.

**REFERENCES:**

[1] http://minerals.usgs.gov/minerals/pubs/commodity/helium. [2] Baig, T. et al., Accepted 2014 *Supercon. Sci. Tech.* [3] Lvovsky, Y. et al. *Supercon. Sci. Tech.* **26**, 093001 (2013). [4] Iwasa, Y. *Case Studies in Superconducting Magnets* (Springer, New York, 2009). [5] Cosmus T C and Parizh M., *IEEE Trans. Appl. Supercond.* **21(3)**, 2104, (2011). [6] Ristic, M. et al., *IEEE Trans. Appl. Supercond.* **21(5)**, 3501, (2011). [7] Stendvall A. et al., *IEEE Trans. Appl. Supercond.* **19**, 2403, (2009). [8] Douglas, J., *Numerische Mathematik* **4**, 41 (1962). [9] Huang, X. et al., *IEEE Trans. Appl. Supercond.* 20(3), 2091, (2010).