Efficient Method to Evaluate the Heating Risk of Coils

Lin Liu[1], Liang Xuan[2], and Qiong Zhang[3]

[1]MR, GE Company, Beijing, Beijing, China, [2]MR, GE company, Waukesha, WI, United States, [3]MR, GE company, Beijing, Beijing, China

Introduction: For MR system, it is safety requirement to evaluate the heating effect of the coils. Accordance with requirements stated in [1] for patient and operator safety, temperature throughout the entire test shall be less than 41 ^{0}C. During the coil development and integration, GE Healthcare conducts strict test to demonstrate surface coils safety. The test will take 2.5 hours with the specified protocol. Since the test will be executed under plugged and un-plugged situations, it is time-consuming with the risk to damage the coil. Here, we presented an efficient and safe method to evaluate the heating effect of coils by using the method of curve fitting and extrapolation.

Methods: According to the industry test methods and rules, a curve fitting and data extrapolation method is developed. Heat test basically can be described by following model, $U_t = \alpha\left(U_{xx} + U_{yy} + U_{zz}\right) + f(x, y, z, t)^{[2]}$ (1); $U(x, y, z, 0) = g(x, y, z)$ (2); Where $-\infty < x < \infty, -\infty < y < \infty, -\infty < z < \infty, 0 < t < \infty$, and $\alpha = k/(c_p \cdot \rho)$ is the thermal conductivity, a material-specific quantity depending on the thermal conductivity k; the mass density ρ; and the specific heat capacity c_p. U is the temperature. Assumption 1: The ambient temperature in the scan room is a constant, $g(x, y, z) = g$; Assumption 2: Heat source is a point source, typically a decoupling circuit, and heat comes from constant DC and RF heating, and this situation does not change during the heat test. Thus $f(x, y, z, t) = f(x_1, y_1, z_1)\delta(x - x_1)\delta(y - y_1)\delta(z - z_1)$. The solution of equations (1) and (2) then can be expressed as $U(x, y, z, t) = [f(x_1, y_1, z_1)/(4\sqrt{2}\pi r\alpha)] \cdot \mathrm{erfc}\left(r(2\alpha t)^{-\frac{1}{2}}\right) + g$, where $r^2 = (x - x_1)^2 + (y - y_1)^2 (z - z_1)^2$. In general, hot source can be described by function $U(x, y, z, t) = a\,\mathrm{erfc}(bt) + c$, where $\mathrm{erfc}(x) = \frac{2}{\sqrt{\pi}}[\int_x^\infty \exp(-t^2)dt]$, which is used as the fitting and extrapolation model. A MATLAB tool is developed base on this model. To evaluate this method, we did the heating test by the routine method (TR/TE/Flip/BW/NEX/slice =18/7/180°/15.64/150/10mm, Matrix=256*256, FOV=400mm), on 44 coils with 52 test modes in all. 3.0T and 1.5T MR scanners (Table 1) were used for this test with 2.5 hours per test. The 1st hour test data, through comparison between five kinds of time length (Figure 1), is finally selected to calculated the coefficients a, b, and c and finish the curve fitting to get the simulated result for whole test. Comparing the simulated curves and the measured results, the efficiency of this method was concluded.

Results: Heat test is advanced carried out based on both empirical and extrapolation method. By paired t-test (p-value=0.104) result, there is no significant difference between these two methods. In addition, from deviation analysis and validation results against coils' performance, the extrapolation method is conservative, which means the highest extrapolated temperature is higher than empirical temperature at the same moment, and which reduces the risk of missing the overheating, too. Figure 2 shows partial measured highest temperature until the end of 2.5 hours scan. Max difference between two curves floats in a range of no more than 0.2 ^{0}C. Figure 3 indicates the same conclusion that this new method accomplishes a good speculated fitting of the experimental situation.

Table 1 Coil and MR system information

System Name	Coil Amount	Test Mode
Discovery MR450 1.5T	19	24
Discovery MR450w 1.5T	8	9
Discovery MR750 3.0T	17	19

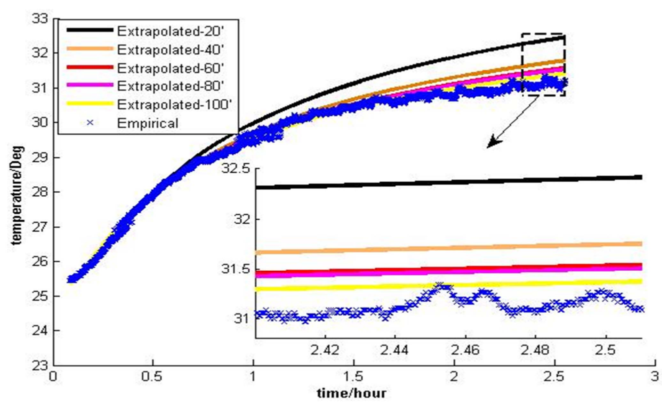

Figure1 Curve fitting using first 20 to 100 minutes data as fitting data and extrapolation on 12Ch Body Array Coil heat test data.

Discussion: From the comparison between empirical and extrapolated results, this fitting and extrapolation method can be introduced as an effective and alternative way to evaluate the heating risk of coils. Meanwhile, with the secondary calculation using the MATLAB tool, the total scanning time can be reduced to only one hour, which will improve the work efficiency to evaluate the heating effect of coils, and reduce the risk to damage the coils under test. From the perspective of application, after some more detailed and targeted model modification, it's possible to set up more accurate mathematic mode by using materials coefficients in future use, thus, this method would reduce the test time to less than half an hour and would do greater effort to assessment for coils and some other MR products such as wireless appearances, etc.

References:

[1] IEC 60601-1 clause 42.3 [S]. 2005.

[2] Thambynayagam, R. K. M. The Diffusion Handbook: Applied Solutions for Engineers, [M]. McGraw-Hill Professional. 2011.

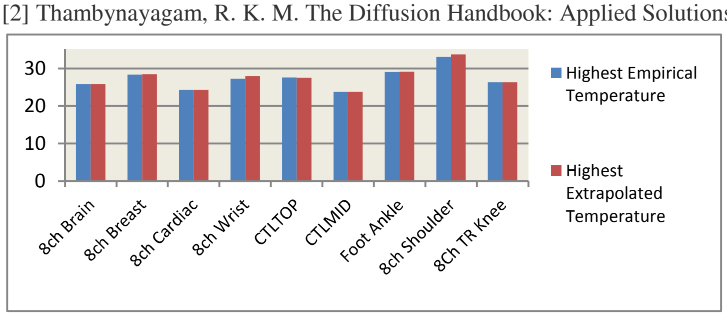

Figure2 Highest temperature of heat test for Discovery MR450w coils: empirical and extrapolation result (Unit: V/Deg).

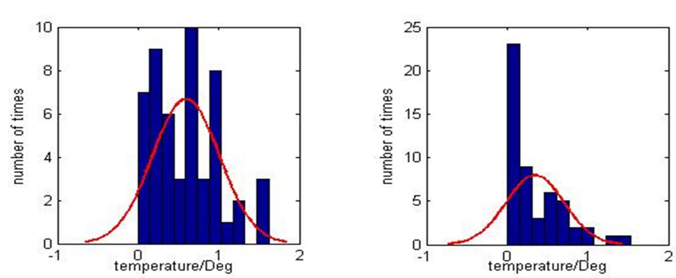

Figure3 Distribution of max difference (left) and peak temperature difference (right) between empirical and extrapolated.