A Design-of-Experiments Approach to FEM Uncertainty Analysis for Optimizing Magnetic Resonance Imaging RF Coil Design

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Abstract

Using the RF Module of the COMSOL Multiphysics® general purpose finite element method (FEM) analysis software package, we computed the magnetic flux density norm profiles at various frequencies in the inner water tube of a prototype birdcage coil typically found in Magnetic Resonance Imaging (MRI) applications as shown in Figures 1 and 2 (courtesy of the National Institute of Radiological Sciences, Chiba, Japan). We found that at the first resonance frequency, the magnetic flux density norm profiles are highly non-uniformly distributed. We then develop a dimensionless metric for the non-uniformity of the profile as a guide for assessing and improving the design of such a prototype birdcage coil. In this paper, we present a design of experiments (DOE) approach to the FEM uncertainty analysis of a birdcage coil such that its magnetic flux density non-uniformity metric can be reduced in an optimized design. We illustrate our approach with a numerical example where seven factors, X1, X2,..., X7, out of a total of 71 design parameters, were selected for a 2-level fractional factorial orthogonal design of FEM simulations involving just 16 COMSOL RF runs plus a center point. A typical output of the DOE approach, as shown in Figure 3, is the matrix showing 3 significant interaction effects, X2-X4, X3-X5, and X6-X7, one dominant direct effect, X2, and three significant direct effects, X3, X4, and X5. Another output, as shown in Figure 4, is the 95% confidence bounds plot for the magnetic flux density non-uniformity metric based on an approximate two-dominant-factor model (which happens to be X2 and X3 in our example). Both results are interpreted to yield a strategy to assess and improve the 71-factor prototype NIRS MRI birdcage coil design. Significance and limitations of the DOE approach to FEM uncertainty analysis as a design tool for MRI applications are presented and discussed. Note: This paper is a contribution of the U.S. National Institute of Standards and Technology, and is not subject to copyright.

Figures used in the abstract

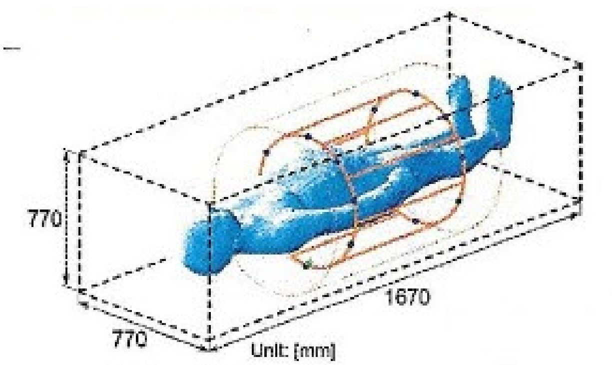

Figure 1: A Typical MRI Imaging Setup with a Birdcage Coil (Courtesy of NIRS, Chiba, Japan).

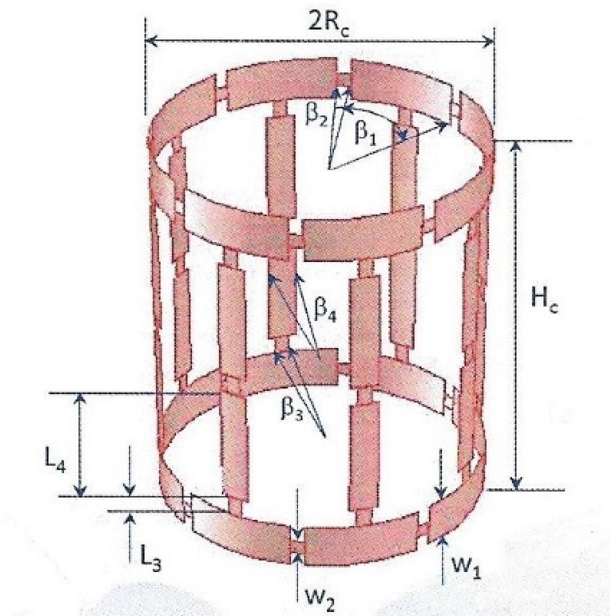

Figure 2: Geometry of a NIRS Birdcage Coil (Courtesy of NIRS, Chiba, Japan).

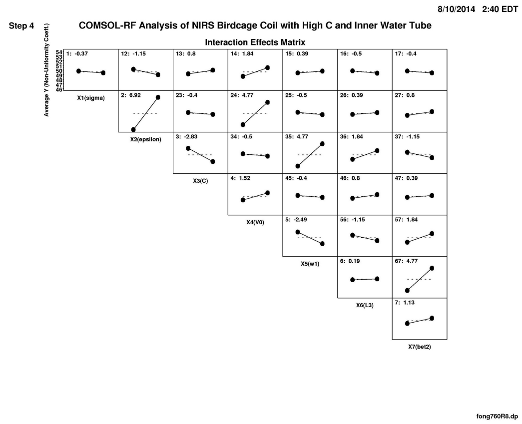

Figure 3: A Typical FEM Uncertainty Analysis Matrix Showing 3 Significant Interaction, one Dominant Direct, and 3 Significant Direct Effects.

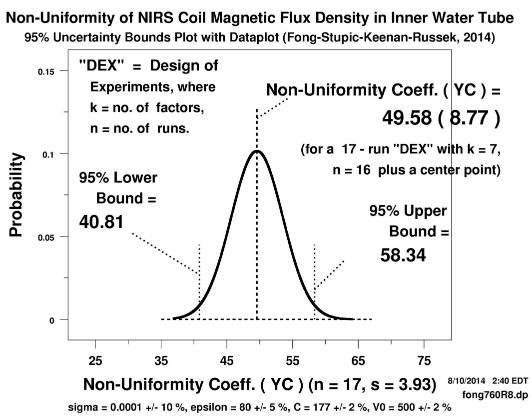

Figure 4: A Typical Uncertainty Analysis Result Showing 95% Confidence Bounds of a Non-Uniformity Metric for the COMSOL Estimate of the Magnetic Flux Density Norm in the Inner Water Tube of a NIRS Birdcage Coil.