Vibration Analysis and Measurement of a Gradient Coil Insert in a 4T MRI

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Introduction

Ongoing development of magnetic resonance imaging (MRI) technology is resulting in ever more powerful scanners, with high static magnetic field strength (7-8T) and high gradient coil current switching speeds. It is generally acknowledged that a serious limiting factor in the development of these machines is the acoustic noise that they generate during scanning [1]. Considerable efforts have gone into the design of "quiet" gradient coils [2]. Switched electric current within the windings of a gradient coil in the presence of a high static magnetic field will produce Lorentz forces, which in turn generate vibration of the gradient coil. Vibration of a gradient coil in a direction normal to the surface will result in acoustic noise. To fully understand the vibration characteristics of a gradient coil, an FE model was developed based on the dimensions of the structure and concentration of copper windings. The objective of this paper is to show the experimentally validated vibration prediction results generated using an FE model of a gradient coil insert.

Materials & Methods

To investigate the vibration behavior of a gradient coil insert in a 4T whole-body scanner, an FE model was created using SDRC I-DEAS software. In the FE model, three layers of elements were used to simulate the copper windings, with another two layers of elements to simulate the cooling tubes inside an epoxy shell. To depict the different concentrations of windings in the copper layer, the FE model was modified based on these concentrations. To validate the FE model, modal testing was conducted on the coil in a free-free state (no fixed supports). The Frequency Response Functions obtained from the data acquisition and analysis system were exported to modal analysis software to obtain the modal frequencies and mode shapes. Boundary constraints were added to the validated FE model and vibration analysis was conducted under swept sinusoidal waveforms from 100 to 3000Hz acting on the X windings only. Again experimental vibration testing was performed when the gradient coil is seated on the patient bed in a 4 T MRI under the swept sinusoidal excitation. A comparison was made of the vibration resonances and vibration deflection shapes both from the FE model based vibration analysis and the experimental vibration measurements.

Results & Discussions

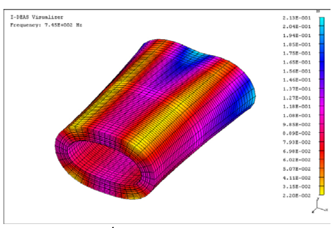

Figure 1: 1st mode from FE analysis (approximately 745Hz)

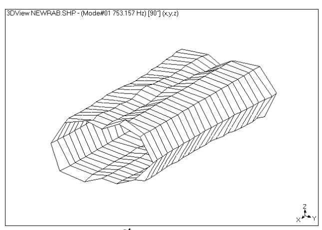

Figure 2: 1st mode from modal testing (approximately 753Hz)

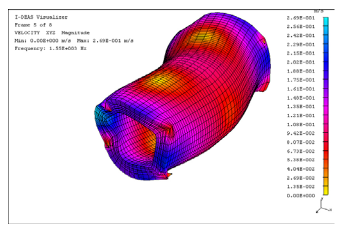

Figure 3: FE Vibration deflection shape (approximately 1550 Hz)

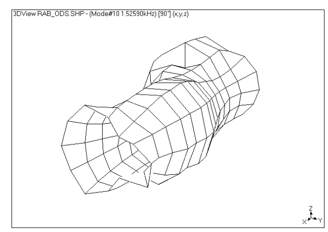

Figure 4: Vibration deflection shape from measurement (approximately 1526 Hz)

From the experimental results it was found that the first mode (natural frequency) was close to 750Hz and that there were 15 modes in total. The natural frequencies and mode shapes in the frequency range from 1 to 3100Hz were also obtained from the FE model. By comparing the corresponding modes from FE based modal analysis and the experimental modal testing, it was seen that only one mode not detected by the FE analysis. Figures 1 and 2 show the mode shapes from the FE model and experimental tests respectively. The mode shapes are exactly the same and the modal frequencies are very close. The average deviation in frequency between the two methods was less than 5 percent. Vibration analysis based on the validated FE model with boundary constraints in place under swept sinusoidal input shows that all resonance frequencies were shifted to higher frequencies. The vibration deflection shapes indicate a strong X direction bias due to the excitation of only the X windings. Figures 3 and 4 show vibration deflection shapes both from FE model and experimental vibration measurement. The shapes are the same and the vibration resonance frequency predicted by the FE model is very close to that from experimental vibration measurement.

Conclusions

A comparison of the modal analysis results from a FE model and modal testing showed very close agreement. The predicted vibration response from the FE model with boundary constraints under swept sinusoidal excitation was very close to that obtained from vibration measurement under the same constraints and excitation in a 4T MRI. Validation of the FE model has therefore been verified through modal testing and experimental vibration testing.

References

1. Rutt BK, Safety Issues in MRI. Plenary Address, 11th ISMRM, 2003. 2. Edelstein WA, Hedeen RA, Mallozzi RP, El-Hamamsy SA, Ackermann RA, Havens TJ. Making MRI Quieter. Magnetic Resonance Imaging 2002, 20: 155-163