Control of Gradient Coil Natural Frequency using a Topology Optimization Technique

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Introduction

Although current MRI (Magnetic Resonance Imaging) technology has tremendous advantages in medical diagnostic and research applications, one of its deficiencies is the high level of acoustic noise generated during scanning. The acoustic noise is generated from MRI hardware components, including the gradient coil assembly, the radio-frequency (RF) coil and the static magnet warm bore. One of the primary sources of noise is the gradient coil assembly. During the imaging process strong electric currents flowing through the gradient coils interact with the static magnetic field. The resultant Lorentz forces are distributed over the gradient coils and act to deflect the gradient coil structure. It is important that these vibratory excitations do not occur at resonant frequencies of the gradient coil structure. Active and passive methods are commonly used for controlling vibration/noise of a structure. Due to the frequency limitation of active methods, a passive method involving attaching a viscoelastic damping material to the outer surface of the gradient coil is proposed by the authors and tested in simulation.

Methods & Results

To analyze the vibration behavior and obtain the optimum results of a gradient coil, an FE model was built using ANSYS v.10 software linked to FORTRAN in-house code. In the FE model, two layers of solid elements were used to simulate: one was the gradient coil structure layer, the other was the viscoelastic damping material layer (Figure 1). For validation purposes, the FE model compared natural frequencies with those of a previous model composed of shell elements [1]. The objective function was a specific natural frequency and the design variable was density with respect to each element. The design variables are the elements, which number 750 in this study, composing the viscoelastic damping material. A design sensitivity analysis was conducted because the gradient-based method is widely used to search for local optimum points. To validate the correctness of the design sensitivity, the results were compared to finite difference results. The results were in good agreement.

The topology optimization problem was based on the power-law approach. The Young's modulus and mass were assumed as $E = E_0\rho^n$, $m = m_0\rho$ where n is the penalization power (typically n=3) and ρ is the vector of design variables with respect to each element. The optimization problem could be solved using several different approaches such as Optimality Criteria (OC) methods, Sequential Linear Programming (SLP) methods or the Method of Moving Asymptotes (MMA) and others. This work used a standard OC-method and a filtering technique which worked by modifying the element sensitivities [2]. Figure 2 shows the only optimal topology design for the damping material. The black area shows where damping material is needed. There is no need for damping material in the white area because the displacement of the white parts is almost zero. This result is also seen in Figure 3 where the displacement of the blue areas are almost zero. Figure 4 shows the iteration history of the objective function. The initial value was 0.5. The total time consumed to reach the final result was almost 100 minutes (CPU 2.0GHz and 1.0Gbyte RAM).

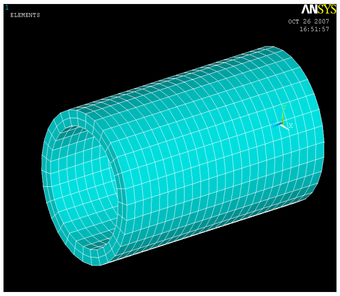


Fig. 1 Solid model with VEM

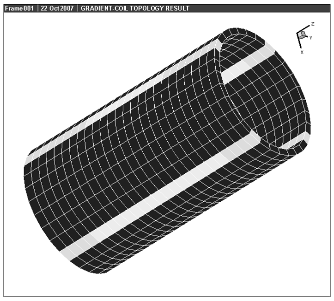


Fig. 2 Optimum damping material

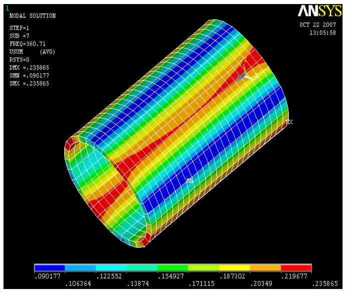
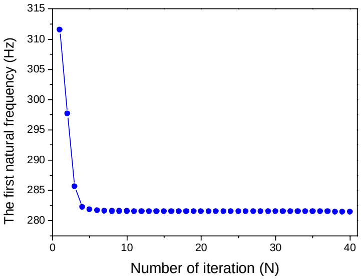


Fig. 3 The first eigenmode



Fig, 4 The history of the objective function

Conclusion

Placement of the viscoelastic damping material at the optimum topology on the gradient coil would reduce the natural frequency response. Controlling the natural frequencies of the gradient coil could avoid resonant phenomena, enabling greater resolution in images and a more comfortable patient environment. Future work will consider maximization of damping effects of the specified mode of the gradient coil with viscoelastic damping material using the topology optimization technique. The design variables will be density or thickness with respect to each element.

Acknowledgements

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References

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