

Acoustic noise simulation and measurement of a gradient insert in a 4 T MRI

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Received 5 January 2004; received in revised form 9 November 2004; accepted 30 November 2004

Available online 25 February 2005

Abstract

High speed switching of current in gradient coils within high magnetic field strength magnetic resonance imaging (MRI) scanners results in high acoustic sound pressure levels (SPL) in and around these machines. Many studies have already been conducted to characterize the sound field in and around MRIs and various methods have been investigated to attenuate the noise generated. In the work presented here a computational vibro-acoustic model was developed based on an iteratively modified and validated finite element (FE) model to characterize the acoustic noise properties of the gradient coil. The simulation results from the computational model were verified through experimental noise measurement for the gradient coil insert in a 4 T MRI scanner by using swept sinusoidal time waveform inputs. Comparisons show that the computational model predicts the noise characteristic properties extremely accurately. There are three dominant frequency bands where the SPL is much higher than those at other frequencies. The SPL in the horizontal direction is much higher than that in the vertical direction due to the excitation to the horizontally placed X coil. The SPL to the inner surface of the coil is higher than far from the inner surface, which proves that the acoustic noise is radiated from the inner surface and primarily caused by the normal vibration of the inner surface. Further verification was conducted by using two types of trapezoidal sequence inputs usually used, which is to simulate real scanning sequences for small animals. Again the accuracy of the developed model is verified. The validated acoustic computational model could be

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used as an effective method to predict the noise that would be produced by a coil in the design stage. Modification of the structural design or the excitation pulse could be performed to reduce the acoustic noise when the gradient coil is in scanning.

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Keywords: Acoustic noise; MRI scanner; Gradient coil; Modeling

1. Introduction

Ongoing development of magnetic resonance imaging (MRI) technology is resulting in ever more powerful scanners, with high static magnetic field strength (7–8 T) and high gradient coil current switching speeds. These developments are driven by the desire to obtain higher quality images that reveal more detail of the internal structure of the biological subjects being examined. It is generally acknowledged that a serious limiting factor in the development of these machines is the acoustic noise that they generate during scanning [17]. The main source of this acoustic noise is the gradient coil, which is used to produce a spatially varying dynamic magnetic field inside the MRI bore [15]. The high acoustic noise generated by the gradient coil results in problems for patients and health care workers that range from simple annoyance to difficulties in verbal communication, heightened anxiety, temporary hearing loss and possible permanent hearing impairment for persons who are exposed to these noisy environments for long periods of time. The vibration of the gradient coil that generates the acoustic noise will also affect the image quality and resolution since the radio frequency receiver is often integrated into the gradient coil [19]. It is therefore important to find ways to reduce the vibration and acoustic noise levels of MRI scanners in order to improve both the image resolution and the patient and working environment in and around the scanners.

To create a gradient magnetic field during scanning a time varying current is applied to the gradient coil windings. In the presence of the high static magnetic field this generates a Lorentz force distribution that acts on the coil. This time varying force distribution results in vibration of the gradient coil during scanning. The forces acting on the coil generate movement of the coil surface and subsequently the acoustic noise within and nearby scanners. The investigation of MRI gradient coil associated acoustic noise was first conducted in the late 1980s [8]. This work investigated the acoustic noise generation mechanisms involved, measurement instrumentation that was best suited for work inside and nearby scanners, and different test procedures. Later, extensive studies were performed using various MRI scanners and different pulse sequences [18,11,4,19,16,1]. Acoustic noise levels ranging from 80 to 130 dBA were reported and found to depend on the scanner field strength and pulse sequence.

Considerable effort has also gone into the design of new “quiet” gradient coils, development of active noise cancellation (ANC) techniques, and passive noise isolation for use on MRI machines [3,2,5,12,13,7]. Finite element analysis (FEA) as

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