Spatial Measurements and Estimation of Acoustic Noise in a 4T MRI Scanner

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High-field, high-speed magnetic resonance imaging (MRI) scanners generate high-intensity acoustic noise which causes side effects such as discomfort, anxiety and hearing loss in patients and health care workers. For instance, the echo planar imaging (EPI) sequences may produce sound levels as high as 115 dB(A) under certain circumstances, requiring the exposure time to be less than 15 minutes per day. To reduce and control the noise levels during MRI scanning, an in-depth understanding of the sound field inside MRI scanners is highly desirable. This paper presents the results of noise measurements in a 4 Tesla scanner. The spatially distributed frequency response functions (FRFs) were also derived. The FRFs describe the distribution of the sound field inside the scanner and its transmission characteristics. To validate the FRFs, comparisons were made between acoustic responses estimated using the FRFs and acoustic responses measured directly from echo planar imaging (EPI) gradient coil excitation input sequences. The comparisons show that the acoustic responses from both analysis paths are similar to each other across all the frequency spectrum components of interest. The derived FRFs were then used to estimate the spatial noise distributions within the MRI and again comparisons with measured results showed a close similarity.

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1. INTRODUCTION

Magnetic resonance imaging (MRI) scanners are used to map body structures and functions for both medical diagnosis and clinical research. In particular, high magnetic field scanners, which are able to produce rapid images with high resolution and signal-to-noise ratio (SNR), are becoming increasingly common. However, the high-field scanners also produce acoustic noise with high sound pressure levels (SPLs). In MRI scanners, one of the primary sources of noise is the gradient coil cylinder. Electric current, in the form of rapid pulses, passes through the windings of the gradient coil cylinder within the static magnetic field. Lorentz forces are generated on the windings and cause the gradient coil cylinder to vibrate and radiate sound. The radiation of the sound can be transmitted through the air and solid structures surrounding the scanner.

Although it has been reported in a recent study that exposures to high magnetic fields (1 T to 8 T) have posed no demonstrable risk to human health over the past century, the associated acoustic noise could induce a number of side effects both psychologically and physically.[1] For instance, the loud noise may cause difficulties in verbal communication, heightened patient anxiety, and hearing damage.[2]

The noise generated during MRI scanning can reach extremely high levels. Rivicz et al. reported an unweighted peak noise level of 138 dB (ref. 20 μPa) from the measured sound pressure waveform in a 3T imager using an echo planar imaging (EPI) sequence.[3] Foster et al. observed A-weighted peak sound levels between 123 and 132 dB(A) during EPI scanning in a 3 T scanner.[4] In a 4.7 T system, Counter et al. recorded the sound level as high as 130 dB(A) using rapid acquisition with enhancement (RARE) sequences.[5] Exposure to the above acoustic environments, even for a short time, would exceed the recommended limits for occupational exposure to noise.[6]

To reduce the gradient noise levels, several methods have been employed in practice. These methods range from conventional active noise cancellation and passive noise isolation, to novel modifications of gradient pulses and the MRI structure. Significant reduction (20-40 dB) of the sound levels have been achieved under certain conditions.[2,7-9]

A comprehensive understanding of the acoustic noise characteristics inside a particular MRI is desirable before applying specific noise reduction methods.[3] A large amount of work has been conducted in an effort to characterise the noise inside MRI scanners.[10-14] However, this work has focused on characterising the noise due to one or more specific scanning sequences (i.e., EPI, trapezoidal, etc.). Hence, it is impossible, using individual sequences, to derive a generic description of the sound field distribution and transmission inside the scanner.

To study the vibration and acoustic characteristics of gradient coils, several numerical methods have been proposed recently. Kuijpers et al. compared the results of theoretical analysis and numerical modelling of the sound radiation from MRIs under certain idealised situations in an effort to characterise the MRI noise generating mechanism.[15] Mechefske et al. compared the acoustic measurement results within the head/neck gradient coil cylinder with finite-element-(FE)-based and analytical simulations. Both comparisons showed close agreement.[16] Nonetheless, it is difficult to apply the above theoretical and numerical methods to analyse the acoustic response of commercially available scanners due to the lack of gradient coil design parameter detail available and the complicated physical structure (e.g., epoxy-potted windings) of the coil and surroundings.

In their pioneering paper, Hedeen and Edelstein proposed making measurements of the acoustic transfer function at a