Method for reducing gradient acoustic noise for an MR sequence.

L. S. Petropoulos[1,2], P. Margosian[1], D. Lampman[1], V. Taracila[2], R. W. Brown[2]

[1]Hitachi Medical Systems America, Twinsburg, Ohio, United States, [2]Physics, Case Western Reserve University, Cleveland, Ohio, United States

Introduction

In recent years, acoustic noise has become one of the major concerns regarding new generation MR systems. It has been reported that excessive acoustic noise levels (exceeding 123 dB) occur for certain high resolution ultra fast sequences on high field MR scanners. Such noise levels can severely compromise patient comfort and safety. The situation worsens for ultra high field MR scanners (3.0 T and above) when they are equipped with very strong gradient fields. In such cases, the magnitude of the acoustic noise might prohibit the optimum use of a desired sequence. Various researchers have concentrated their efforts on identifying [1], analyzing [2] and proposing ways to reduce acoustic noise [3], [4]. Their main efforts are focused on encapsulating the gradient coils into a vacuum [5], introducing additional elements into the gradient structure to increase its rigidity [3], or attempting to reduce the noise of the surrounding structures, especially the noise generated by eddy currents on the main magnet's warm bore [6].

In the present paper, an alternative methodology for reducing gradient acoustic noise is proposed. Instead of concentrating towards altering the mechanical and/or electrical shape of the gradient coil structure, it is proposed to slightly modify specific sequence parameters, such as TR and bandwidth, without compromising image quality. The choice of these parameters is to be made such that the inherent frequencies of the desired sequence do not coincide with normal mechanical excitation modes of the gradient structure. This methodology was validated on a Hitachi 1.5 T Echelon™ MR scanner. We show that it is possible to reduce the peak acoustic noise level of 3D TOF sequence and a 2D GE sequence by as much as 7 dB by simply modifying the TR times, while the penalty to the overall scan time is less than 0.8 sec.

Methods

It has been shown[7] that for a gradient coil structure, the general system of 3 inhomogeneous equations of vibration (in Flugge's approximation) including external Lorentz forces, resulting from the interaction between the main magnetic field and x, y and z gradients, generates a spectrum of normal modes characteristic to the gradient coil design. In addition, the choice of various sequence parameters also leads to a frequency spectrum associated with the specific sequence. The level of the acoustic noise for a particular sequence can then be estimated by evaluating the average acoustic power as

$$\langle P \rangle \propto \sum_{n=0}^{n_{\max}} \sum_{m=1}^{m_{\max}} \sum_{l=1}^{\infty} \frac{l^2 \omega_R^{\,2} \omega_{mn} \left| g_{z,mn} c_{z,l} + g_{y,mn} c_{y,l} + g_{x,mn} c_{x,l} \right|^2}{\left(\omega_{mn}^2 - l^2 \omega_R^{\,2}\right)^2 + \left(2\beta l \omega_R \omega_{mn}\right)^2} \qquad (1)$$

where ω_{mn} are the normal modes of the gradient cylinder, m and n correspond to the gradient's axial and circumferential wave numbers, respectively, and $\omega_R = 2\pi / T_R$ (T_R is the sequence repetition time).. In addition, $g_{x,mn}, g_{y,mn}, g_{z,mn}$ represent the Fourier transforms of the Lorentz forces. The Fourier series coefficients $c_{x,i}, c_{y,i}, c_{z,i}$ are defined through $T_{(x,y,z)}(t) = \sum_{n=-\infty}^{\infty} c_{(x,y,z),n} e^{in\omega_R t}$ with $T_{(x,y,z)}(t)$ representing the gradient temporal behavior of the read, phase encoding and slice selecting gradients, respectively. Mechanical characteristics of the gradients include the gradient length L, thickness h, density ρ, Young's and Poisson's moduli, E and ν, and the damping constant β. For a given gradient coil structure, its normal modes are predetermined and fixed. Thus, in order to minimize the acoustic power from the relationship (1), a careful choice of sequence parameters can affect ω_R in a way that a resonance condition is avoided, $\omega_{mn} \neq n\,\omega_R$. Under this condition, the average acoustic power for the gradient coil may be reduced in possibly significant fashion.

Results and Discussion

A 3D TOF sequence with extra crushers applied on all three axes and a 2D GE sequence was chosen to validate the aforementioned methodology. A particular effort was made such that for each of these two sequences the maximum gradient field strength and slew rate were considered. Placing a Norsonic™ model N118 acoustic measuring device inside the MR scanner and in the middle of the bore, the maximum acoustic noise levels were recorded. For the 3D TOF sequence, the TR of the sequence was changed by modifying its bandwidth, while for the 2D GE sequence the overall TR of the sequence was changed without altering any other parameter of the sequence. In addition, for both sequences the overall scan time was recorded. As shown in figure 1, by increasing the TR of the 3D TOF from 14 ms (which the minimum allowable time) to 20 msec, it was possible to reduce the maximum acoustic noise of the scan from 120.1 dB to 113.4 dB, a 6.7 dB difference, while the overall scan time was elongated by 0.76 sec. Furthermore, as figure 2 indicates, by increasing the TR of the 2D GE sequence from 4.7 msec to 7.2 msec, a 7 dB decrease on the overall acoustic noise level was measured, while the overall increase of the scan time was 0.56sec. Further examination of figure 2 indicates that for the 2D GE that there are bands of TR where the acoustic noise level is excessive. As the figure illustrates, even longer TR values often produce higher acoustic noise levels than do shorter TR values. This agrees with our observation that as long as the sequence parameters avoid the excitation of the gradient coil's modes, the acoustic signature of the sequence can be minimized without altering the gradient's electrical or mechanical characteristics.

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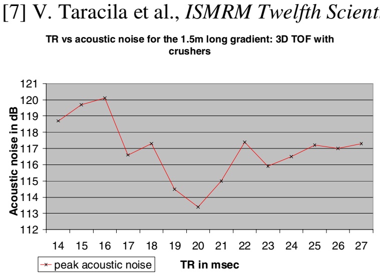

Figure 1.

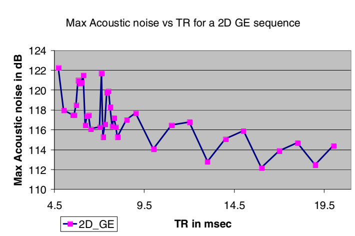

Figure 2