Simulated Noise in MRI Systems Caused by Magnet "Warm-Bore" Eddy Currents

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Overview

In MRI medical diagnostic systems, there is considerable acoustic noise leading to patient discomfort. At higher field strengths, where better images may be constructed, this noise problem worsens. The noise is generated by the interplay between Lorentz forces and the rapid current changes of pulsed gradient-field coils located in magnetic field strengths in the Tesla range. These forces generate stresses in MRI system components, exciting a spectrum of mechanical normal modes. While certain noise sources have been addressed in past research, we focus in this paper on an analytical calculation of the noise generated by eddy currents produced in the "warm bore" of the main magnet MR coil in response to the gradient coil field time dependence.

Theory

An industrial MRI (whole-body) system with a typical gradient coil set is considered (Fig. 1). The mathematical problem of Faraday induction into a cylindrical warm bore has been set up and solved obtaining current density distribution of eddy currents $j(z,t)$ (Fig. 2) with the techniques in [1], [2].

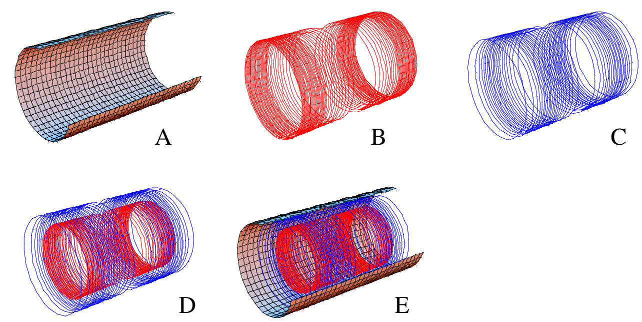

Fig. 1 MRI System: A-"warm bore", B-gradient coils, C active shielding coils, D- gradient and active shielding coils and E- assembled MRI system.

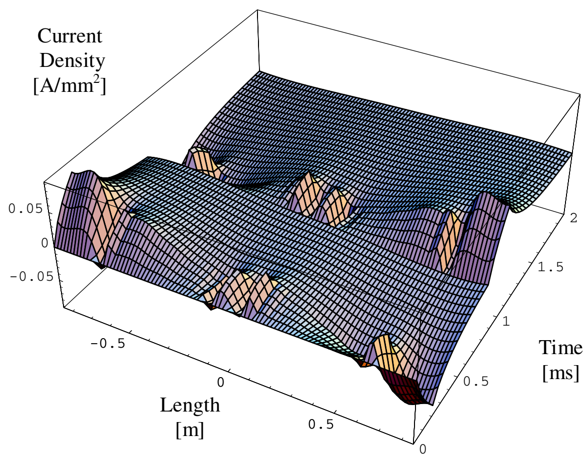

Fig. 2 Current density distribution on "warm bore" as a function of time and position. Peaks occur at 0.2 ms and 0.8 ms corresponding to the start and the end of the driving current plateau time.

The inhomogeneous wave equation for the vibration of the warm bore is constructed [3] with a Lorentz force term generated by eddy currents

$$D\frac{\partial^4 w}{\partial z^4}+\frac{Eh}{R^2}w+2\beta h\frac{\partial w}{\partial t}+\rho h\frac{\partial^2 w}{\partial t^2}=j(z,t)Bh$$

with displacement w of the cylindrical surface from equilibrium in radial direction, the flexural rigidity (bending stiffness) D, Young's modulus E, Poisson's ratio ν, shell thickness d, cylinder radius R, mass density ρ, magnetic field of the main magnet B, warm bore thickness h and damping constant β. The general solution of this equation is found and the total mechanical power is calculated to be

$$\langle P\rangle=\frac{Rh}{2\rho}B^2\frac{T^2L}{2\pi}\sum_{n=1}^{\infty}\int_0^{\infty}\frac{\beta/\rho}{\left(\omega_{0n}-\omega\right)^2+\left(\beta/\rho\right)^2}\left|\mathcal{J}(k_n,\omega)\right|^2 d\omega,$$

with length of the warm bore L, time period T, normal frequency of the corresponding mode $\omega_{0n}=\sqrt{\left(D\left(n\pi/L\right)^4+Eh/R^2\right)/\rho h}$ and wave number of the mode $k_n=n\pi/L$.

Results

The total calculated mechanical power of radial modes for a typical commercial MRI system is found to be 2.36 mW (93.7 dB) while the Joule power is 1.26 W. This result is consistent with experimental data [4], where the noise generated by "warm bore" in different gradient sequences is measured to be 93-96 dB. This method provides a way to determine the analytical acoustic transfer function [5]. Such current density calculations can be used to determine mechanical power generated by asymmetric modes (circumferential and bending) in misaligned coils [6].

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