

Vibroacoustic Modeling of Noise in Magnetic Resonance Imagers

Robert A. HEDEEN¹, Richard P. MALLOZZI¹, William A. EDELSTEIN¹, Timothy J. HAVENS²

¹GE Corporate R & D, One Research Circle, Schenectady, NY USA; ²GE Medical Systems, 3001 Radio Drive, Florence, SC USA;

Introduction

Magnetic Resonance Imagers (MRI) are unpleasantly loud for medical diagnostic devices. Noise levels in excess of 115 dBA have been observed at a patient's ear during certain scan sequences [1]. These high noise levels cause problems in patient comfort, doctor-patient communications, and occupational noise exposure for health-care workers. We have developed a vibroacoustic model of a typical MRI, based on a technique known as Statistical Energy Analysis (SEA). The model serves as a guide in understanding the vibroacoustic environment of an imager, for the purpose of quieting existing products and in designing quiet into new products. Experiments have provided data that serve to validate the estimates of subsystem vibration and the final noise level predictions.

Description of the Model

Statistical Energy Analysis relies on the fact that, under certain circumstances, the flow of vibrational energy between coupled mechanical systems is proportional to the difference in average modal energy between them. This condition occurs at frequencies where there is a sufficient density of vibrational modes that the modes are statistically similar. In a structure with the size and construction of an MRI scanner, this happens at frequencies above about 400 Hz. Since most MR scan sequences are composed of multiple harmonics of 100 Hz or so, with harmonic components extending beyond 5 kHz, the majority of MR vibroacoustic energy falls into this statistically valid range [2]. The high frequency content of the noise, the simple, lightly damped structure, and the structural-acoustic interactions involved make MRI scanners well suited to this modeling technique. Application of SEA principles allows us to reduce a complicated vibration problem to a simpler energy balance problem similar to classical conductive heat transfer.

We use a commercially available SEA code known as AutoSEA, which is marketed by Vibroacoustic Sciences, Inc., of San Diego CA, USA. The physical model is depicted schematically in Figure 1.

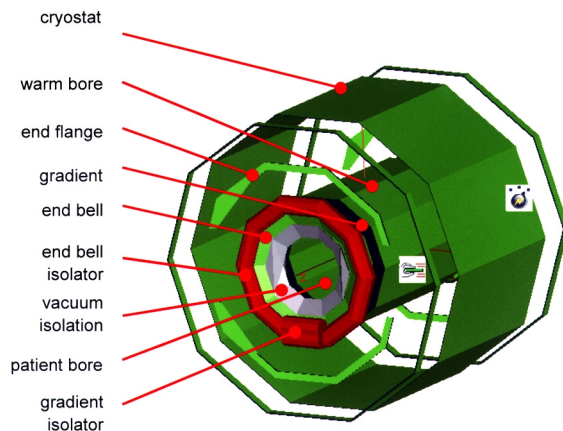


Figure 1. SEA physical model of MR imager.

Per SEA procedures, the MRI scanner model is built up with geometrically simple substructure elements such as plates, cylinders, isolators, acoustic cavities, etc. Physical detail smaller than a wavelength is not required. Basic physical properties of the subsystems, such as density, modulus, and damping are associated with each element. The software introduces coupling loss factors, which determine the "resistance" to energy flow between subsystems, from either basic principles or experimental determination.

Input power to the system is due to two mechanisms. Very large Lorentz ($\mathbf{B} \times \mathbf{i}$) forces in the gradient coils are the prime system excitation. Spectral values of this excitation were obtained by direct measurement of gradient vibration. Because of the high electromagnetic fields involved, eddy current effects in the electrically

conducting substructures also introduce internal sources of vibratory power. The eddy-current induced forces in the magnet bore and end flanges were calculated by a separate analysis.

The SEA model contains a total of 28 subsystems and 53 junctions. Solution of the main energy-coupling matrix takes about 5 minutes on a 266 MHz, Pentium-II laptop computer. Subsequent runs on minor model modifications are completed in less than a minute each. We are primarily interested in the sound pressure inside the patient bore, but we also calculate the vibration spectra of other parts of the scanner, as well as sound pressure in the surrounding test room.

Experimental Validation

We rely on experimental observations for some of the driving excitations and for validation of the results of the analysis. For our measurements we used a standard GE MRI scanner modified to reduce acoustic noise in the patient bore and the surrounding room. Among other features, this experimental system contained elastomeric vibration isolators on the gradient coil and the patient bore tube, a sealed vacuum compartment surrounding the gradient, a magnet bore made of fiberglass rather than the standard stainless steel, and an RF coil mechanically isolated from the patient bore tube. We chose a particularly noisy standard scan sequence, FMPSGR, to evaluate with our SEA model. During the scan, we measured the vibration of the structural subsystems using small accelerometers and the sound level in the acoustic subsystems using well-shielded instrumentation grade microphones. The frequency content of the data signals was obtained by digital octave filters.

Results

Comparison of predicted and measured response spectra are shown in Figure 2 for the subsystem in which we had the most practical interest, the sound pressure level inside the patient bore. The spectra agree very well, especially at frequencies above 400 Hz where the technique has its theoretical validity. The A-weighted overall sound pressure levels, predicted and measured, agree within better than 2 dBA.

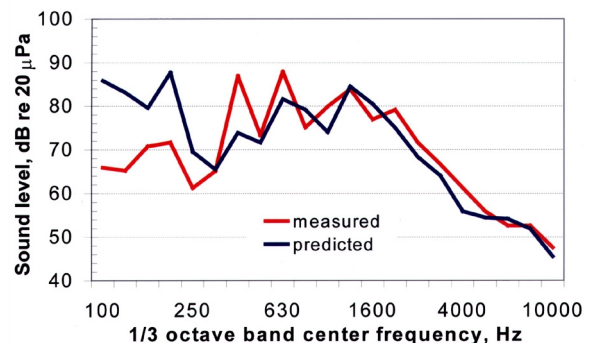


Figure 2. Sound pressure level in patient bore for FMPSGR pulse sequence.

Conclusion

Using this modeling technique, we are able to include noise as a quantifiable design goal in MRI. The simplicity of the model and the speed of its solution allows rapid evaluation of the effect of changes in structure, material, or scan sequence on the patient's noise exposure.

References

- [1] McJury, M.J., "Acoustic noise levels generated during high field MR imaging", *Clinical Radiology* **50**, 331-334 (1995).
- [2] Hedeem, R.A. and Edelstein, W.A., "Characterization and prediction of gradient acoustic noise in MR imagers", *Magnetic Resonance in Medicine* **37**, 7-10 (1997).