Investigation of acoustic noise reduction method for MRI-LINAC hybrid system

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Target audience: MRI engineers who specialize in gradient coil design, acoustic noise reduction and hybrid system development.

Purpose: To find an engineering solution that can reduce gradient-switching induced acoustic noise in an MRI-Linear Accelerator (LINAC) system.

Methods: We propose a novel method to relocate the acoustic field distribution in a split gradient system (see Fig. 1). This method can move the loud areas in the split gradient assembly away from the central imaging area, thus effectively reducing the noise level for patients. This noise reduction scheme stems from beam-deflection theory [1]. If applying a force or moment on a beam, deformation will be produced. The deformation patterns are determined by a number of factors, of which, the boundary condition is a major influence. Assuming there is a beam with pin supports, as is shown in Fig. 2, the deflection of the beam can be calculated by integration of Eq. $\frac{d^2y}{dx^2}=\frac{M}{EI}$, where *y* is the deflection of the beam; *x* is a variable which shows the distance between the free end and the position where deflection occurs; *M* is the moment; *E* is the Young's modulus; *I* is the moment of inertia; *F* is a point force and *L* is the length of the beam. The deflection of the beam can be adjusted by modification of the support position a. Using similar strategy, we may reduce the acoustic noise for the 3-dimensional (3D) split gradient assembly of a MRI-LINAC system. The beam model can roughly represent the longitudinal section of the left gradient cylinder in Fig. 1. If the farther (relative to the gap) supports are moved toward the gap, then the large-displacement areas on the split gradient assembly can be transferred to the outer ends, thus vibration-induced noise can be reduced in the gap region. In order to demonstrate this noise reduction method, a 3D MRI-LINAC acoustic model (without the electronic gun) was established. The model incorporates realistic coil tracks [2] and was analyzed using the finite-element (FE) package ANSYS [3]. The supports [4] were placed at the ends first (as is shown in Fig.2 where a is 0) and then moved to a position closer to the gap (as is shown in Fig. 1 where *a* is 1/3*L*). Harmonic analysis from 100 Hz to 3000 Hz with 30 steps was used to calculate the acoustic field distribution. Only the x coils were energized in this simulation. The peak current on the gradient coils was 600 A and the main magnetic flux density was 1T. Fig. 3 shows the 3D MRI-LINAC acoustic model. Considering the symmetric features of the system, only a quarter of the whole model was established.

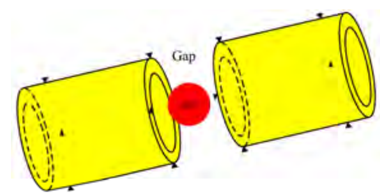

Fig. 1 Diagram of a split gradient assembly with supports.

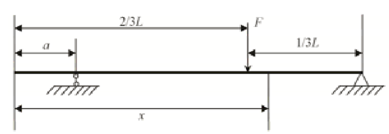

Fig. 2 Diagram of a simply-supported beam. Simply-supported boundary means there is no vertical displacement

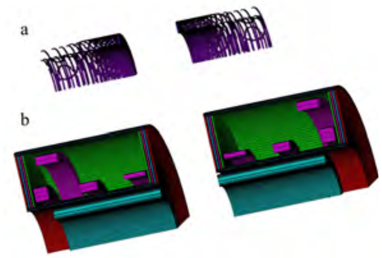

Fig. 3 3D FEM model for the study of acoustic problem in an MRI-LINAC system. (a) The gradient coil track pattern and (b) the split magnet model.

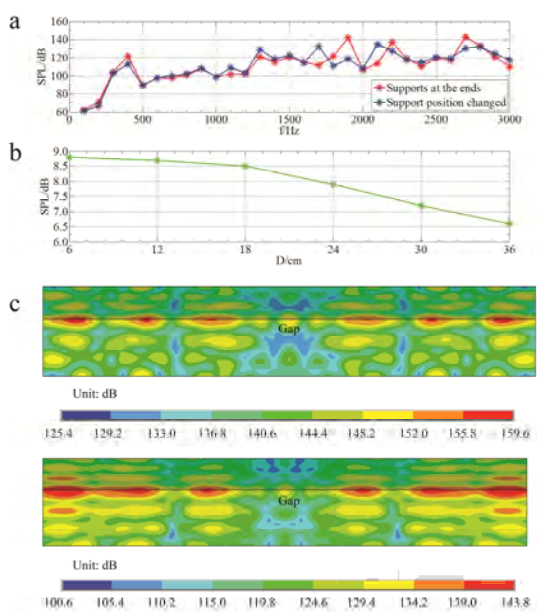

Fig. 4 (a) Acoustic responses at different frequencies. The red line represents the responses when the supports are at the ends and the blue line represents the responses when the farther supports are moving to near positions. (b) Average SPL reduction in the spheres locating at the gap center with different diameters. (c) Acoustic field distribution in the interior of the gradient assembly at 1900 Hz. The upper one is when *a* = 0 and the lower one is when a = 1/3*L*.

Results: The simulated acoustic responses are shown in Fig. 4. Fig. 4 (a) is the average sound pressure level (SPL) in the gap. It can be seen that, when a=1/3*L*, the acoustic responses at dominant resonant frequencies are significantly attenuated, such as 1900 Hz and 2700 Hz. The SPL reductions at these two frequencies are 23.3 dB and 12.5 dB respectively. Moreover, at frequencies lower than 500 Hz, this scheme can robustly produce SPL reduction. For the sampled 30 frequencies, the average SPL reduction in the gap is 8.5 dB. Afterwards, in order to estimate the size of noise reduction area, the average SPLs in spheres (with spherical centers located at the gap center) are calculated. The average SPL reductions for the given 30 frequencies in these spheres are plotted in Fig. 4 (b). The horizontal axis shows the diameter of the sphere. In a sphere with a diameter less than 36 cm, the minimum average SPL reduction is 6.6 dB. The acoustic field distributions (at 1900 Hz) in the interior of the split gradient assembly when *a* = 0 and when *a* = 1/3*L* are shown in Fig. 4 (c). It is easy to see that the loud areas in the split gradient assembly move to the outer ends.

Discussion: From the simulation results (see Fig. 4 (a)), it can be seen that there are some frequencies where the noise levels actually increase using the proposed approach. That is because when the support positions change, the resonant frequencies also change. The resonant effects at these frequencies offset the noise transferring effect. To avoid this issue, future work will be conducted on the support position optimization. When the supports are at optimized positions, the average SPL can be reduced further.

Conclusion: Our theoretical work shows that, the proposed method is effective in attenuating the noise level in the imaging area for the split MRI-LINC system. With further optimization and combined with other strategies, it has the potential to further reduce the acoustic noise of the MRI-LINAC systems and also conventional scanners.

References: [1] R. C. Hibbeler and K. S. V. Sekar, Mechanics of materials. Singapore: Pearson Education South Asia Pte Ltd, 2013. [2] H. S. Lopez, F. Liu, M. Poole, and S. Crozier, "Equivalent Magnetization Current Method Applied to the Design of Gradient Coils for Magnetic Resonance Imaging," Magnetics, IEEE Transactions on, vol. 45, pp. 767-775, 2009. [3] E. Madenci and I. Guven, "Ansys Preprocessor," ed Boston, MA: Springer US, 2006, pp. 83-148. [4] C. K. Mechefske, Y. Wu, and B. K. Rutt, "MRI gradient coil cylinder sound field simulation and measurement," J Biomech Eng, vol. 124, pp. 450-455, Aug 2002.

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