# Numerical Evaluation of Induced Field by Body-motion around High Field MRI Magnets: A case study with an Implanted Pacemaker

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## Introduction

In MRI, patients and occupational workers can be exposed to strong gradients of the static magnetic fields produced by the main superconducting magnet. Previous studies have shown that body motion through these static field gradients can produce substantial currents and fields within tissue [1]. This work focuses on improving our understanding of the interaction of these fields with implanted pacemakers. To handle the boundary conditions between tissues and titanium shell of the pacemaker, an efficient, quasi-static finite-difference scheme [1] incorporating surface impedance boundary conditions [2] is utilized. Numerical evaluations of induced electric fields/current in a tissue-equivalent model of an occupational worker/patient with/without an implanted pacemaker model are presented. The model considers a few static positions as well as the body in motions in and around a 1.5T magnet. With the implanted pacemaker moving through non-uniform magnetic fields, Lorenz forces were computed based on the induced electric current and charge. The methodology presented in this work can be extrapolated to high static field strengths to evaluate motion effect for a variety of body orientations, velocities and implanted devices.

## Method

To accurately model an occupational worker/patient subject to motion through the gradients of a static magnetic field, the torso of the tissue-equivalent Brooks Airforce voxel model (BROOK) was employed. Each voxel was assigned a recently measured conductivity value corresponding to its dominant tissue type and appropriate to the frequency of motion, which was assumed to be ~7 Hz. To numerically evaluate the influence of a realistic magnetic field spatial profile on the body model/pacemaker, the 1.5T Infinion (actively shielded) symmetric magnet was considered. An in-house developed and validated quasi-static finite difference scheme (QSFD) was applied in this investigation. In addition, to handle the titanium shell of the pacemaker/tissue interfaces, a surface impedance boundary condition (SIBC) was introduced. When considering the general SIBC relations, for time harmonic EMFs incident on a conducting medium, the tangential components of electric field $E$ and magnetic field $H$ on the surface are related to each other by $\hat{n} \times E = Z_s \hat{n} \times (\hat{n} \times H)$, where $Z_s$ is the surface impedance. The tangential fields $E_t$ and $H_t$ can be then expressed as $E_t = R_s H_t + L_s\, \partial H_t / \partial\, t$, where $R_s = \sqrt{\omega\mu/(2\sigma)}$ is the surface resistance, $L_s = \sqrt{\mu/(2\sigma\omega)}$ is the surface inductance, $\mu$ and $\sigma$ are permeability and conductivity respectively. These equations define the constant SIBC in QSFD. The electric field distribution on the pacemaker can be discretized and then calculated with the incident magnetic field. Therefore, the potential distribution on the surface of the pacemaker can be retrieved before the scalar potential updating is implemented for the whole body model. In this study, with the induced electric charge and current on the pacemaker, only the Lorenz force was evaluated based on $F_L = q(-\nabla\varphi - \partial A/\partial\, t + v \times B)$, where $q$ is the induced charge and $v$ is the instantaneous velocity of the charge. The scalar potential $\varphi$ and vector potential $A$ were calculated with the aforementioned SIBC scheme. Fig. 1 shows the implanted pacemaker model, with the conductivity assigned to 2.34e6 *S/m* with plastic on top of the pacemaker (see Fig.1) which covers the electric leads.

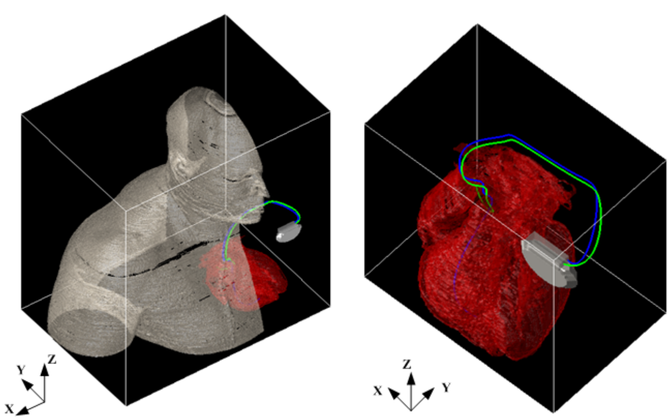


**Fig. 1.** – Sketch of implanted pacemaker in the torso of the tissue equivalent body model; The size of the pacemaker is ~53x43x13 mm.

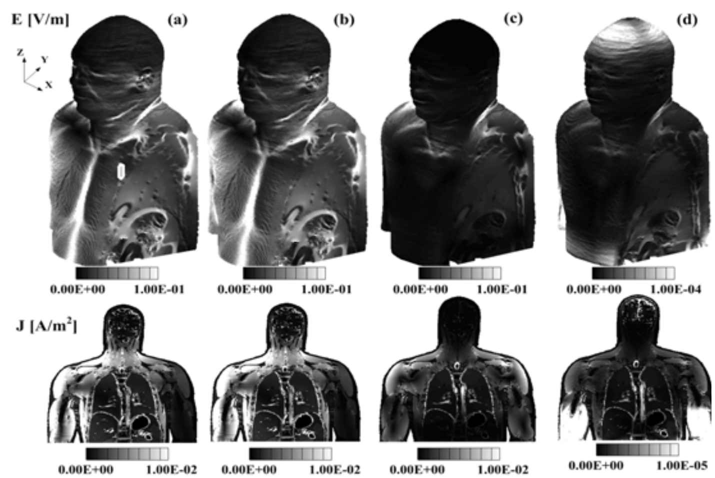


**Fig. 2.** – Sketch of implanted pacemaker in the torso of the tissue equivalent body model; The size of the pacemaker is ~53x43x13 mm.

## Results and Discussion

The interference of induced electric fields and current densities in body tissues due to the implanted pacemaker is, according to the simulation results, not significant. This is expected, as the currents tend to flow in high conductivity media (i.e. pacemaker) rather than low conductivity (i.e. body tissues). Fig. 2 (a, b) shows similar EM inductions in the body while standing near the patient table (position 1), with and without implanted pacemaker. This indicates that the pacemaker distorts the field induction in the tissues only slightly. Fig. 2 (c, d) represents the inductions in the patient lying on the table near the entrance (position 2) and centre (position 3) of the magnet bore. All body motion was assumed to be at a nominal 1 m/s. It can be observed that at positions near strong magnetic gradients, high electric fields and current densities can be induced in the body model above limits set out in the international regulations [1, 2]. The total Lorenz forces on the pacemaker were calculated to be 0.13 *N* at position 1, 0.04 *N* at position 2 and 0.01 *N* at position 3. Assuming that the pacemaker has a mass of about 40 *g,* the accelerations at these positions are 3.25 *N/Kg,* 1 *N/Kg,* and 0.25 *N/Kg* respectively. The force directions are generally against the direction of motion. Compared to the magnetic deflection forces [3] and gravity, the Lorenz force arising from the induced charges and currents on the pacemaker is small. It should be noted that this force is proportional to the magnitude of body velocity and the local magnetic field. When the body model is immersed in higher magnetic gradients and/or moving faster, the induced currents and Lorenz force can become significant.

**Acknowledgements:** Financial support from the Australian Research Council is gratefully acknowledged.

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