Robust Simulation of MRI Gradient Field-Induced Vibration of an Implantable Medical Device

Ihsan Zainul[1], Mahdi Abbasi[1,2], and Gregor Schaefers[1,3]

[1]*MR:comp GmbH, Gelsenkirchen, Germany,* [2]*Faculty of Engineering/ATE, Duisburg-Essen University, Duisburg, Germany,* [3]*MRI-STaR GmbH, Gelsenkirchen, Germany*

Synopsis

The interaction between the gradient induced eddy current and the static magnetic field in the MRI system generates force and torque to a conductive implant if the eddy current magnetic moment and static magnetic field are misaligned. A frequency-domain solver (F-solver) of full-wave simulator CST studio suite 2015 was employed as an initial step to calculate the surface current induced due to the gradient field-induced switching.

Introduction

The rapid switching of the gradient field generated by the gradient coil of an MRI system generates a gradient-induced eddy current magnetic moment. The interaction between the gradient induced eddy current and the static magnetic field in the MRI system generates force and torque to a conductive implant if the eddy current magnetic moment and static magnetic field are misaligned [1]. Force and torque generate a vibration which could create several harmful effects to a patient such as patient discomfort and pain. Therefore, a safety effect regarding the vibration of an implant has become one standard of MRI safety tests. The magnetic force generated on a conductive material is given in the following equation

$$F(t) = I(t) \int (dl \times B_0) \qquad (1),$$

where is current that flows through element wire and represents the static magnetic field. The force as a function of surface current over time t can be formulated as

$$F(t) = \int K(t) \times B_0 \; da \qquad (2),$$

where represents the grid of the implant surface. The surface current induced to an implant described in Eq. (2) is strongly influenced by the gradient field, geometry and orientation of the implant in the scanner. A numerical simulation was performed in order to calculate the surface current over the surface of the implant. Finally, the vibration simulation was derived from the surface current distribution.

Method

A frequency-domain solver (F-solver) of full-wave simulator CST studio suite 2015 was employed as an initial step to calculate the surface current induced due to the gradient field-induced switching. The calculated surface current that conformed the surface of the implant was exported to an in-house developed post processing framework based on Eq. (2). Subsequently, the process was repeated for different phases of the excitation signal. Finally, a trajectory of displacement of the implant over a period of the excitation signal was calculated. Figures 1 and 2 show the calculation of the surface current on a copper disk with radius of 1.5 cm and thickness of 0.5 mm at a frequency of 2.5 kHz for coronal and sagittal orientation respectively. The copper disk was located at the center of a z-direction Helmholtz coil. The Helmholtz coil was modeled as a two-circular wire with radius of 10 cm. The input signal is a sinusoidal signal. The sagittal orientation indicates a higher surface current distribution in comparison to the coronal.

Results

The normalized displacement of both orientations of the copper disk, derived from the mass point force equation are compared in Fig. 3. As shown in Fig. 3, the maximum displacement of the sagittal orientation is higher than the coronal since the vector of static magnetic field and the surface current of the coronal orientation are more aligned. In this calculation, the mechanic influence of the adjacent tissue of the implant was neglected and the implant was assumed as a rigid object. However, this procedure can be implemented to a complex geometry for different orientations.

Conclusion

A simulation procedure of the gradient field-induced vibration of an implant in an MRI system is proposed in this contribution. The force and the displacement were calculated based on the surface current distribution on the implant. Surface current simulations of a copper disk for two orientations were compared to describe the vibration effect. This procedure could be used for a worst-case analysis regarding the orientation of the implant in the gradient coil of an MRI system.

Acknowledgements

No acknowledgement found.

References

[1] ISO/TS 10974 Ed. 1 (2012), "Assessment for the safety of magnetic resonance imaging for patients with an active implantable medical device"; International Standards Organization Technical Specification

Figures

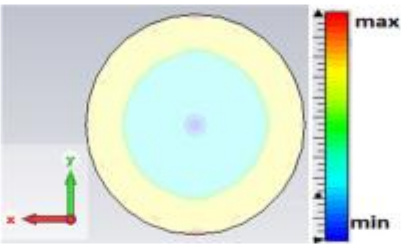


Fig. 1. Surface current distribution (coronal)

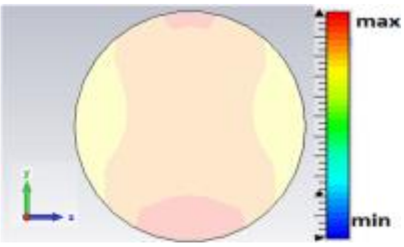


Fig. 2. Surface current distribution (sagittal)

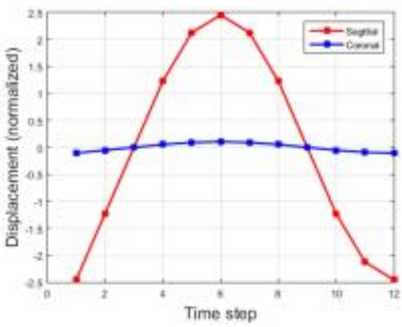
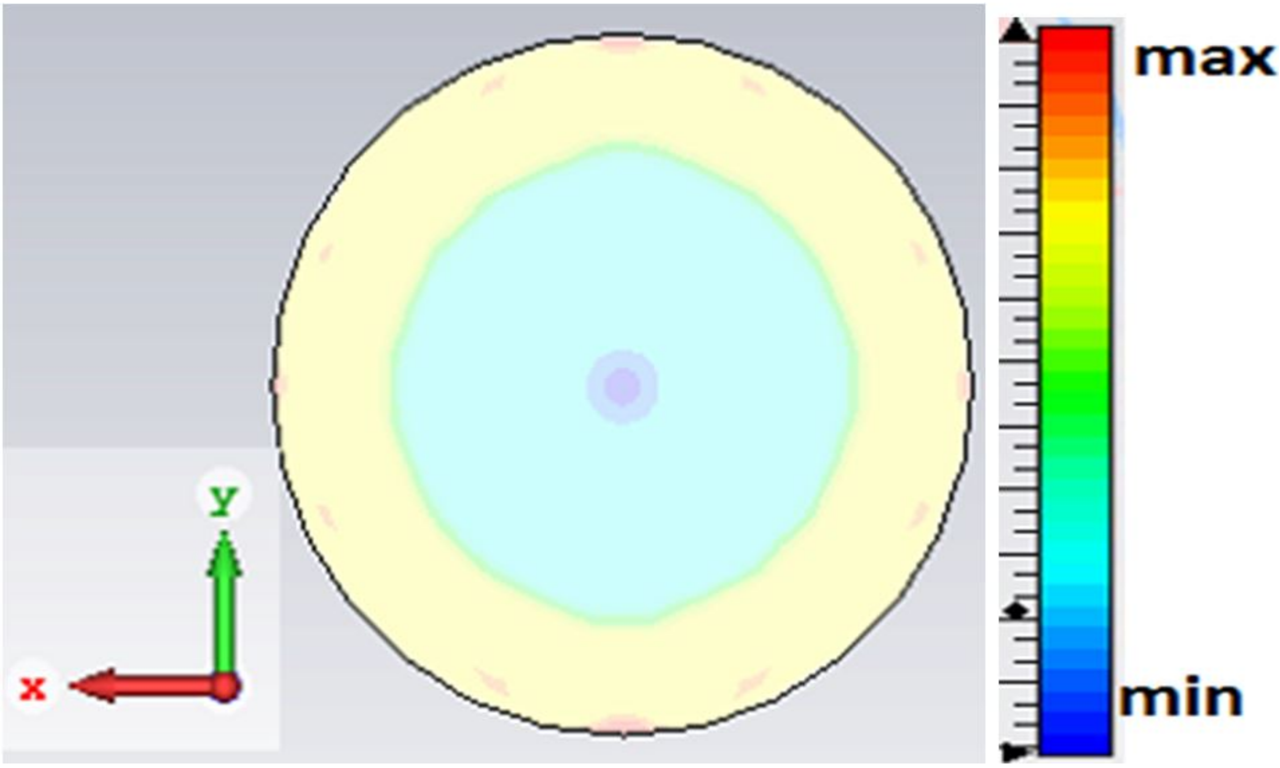
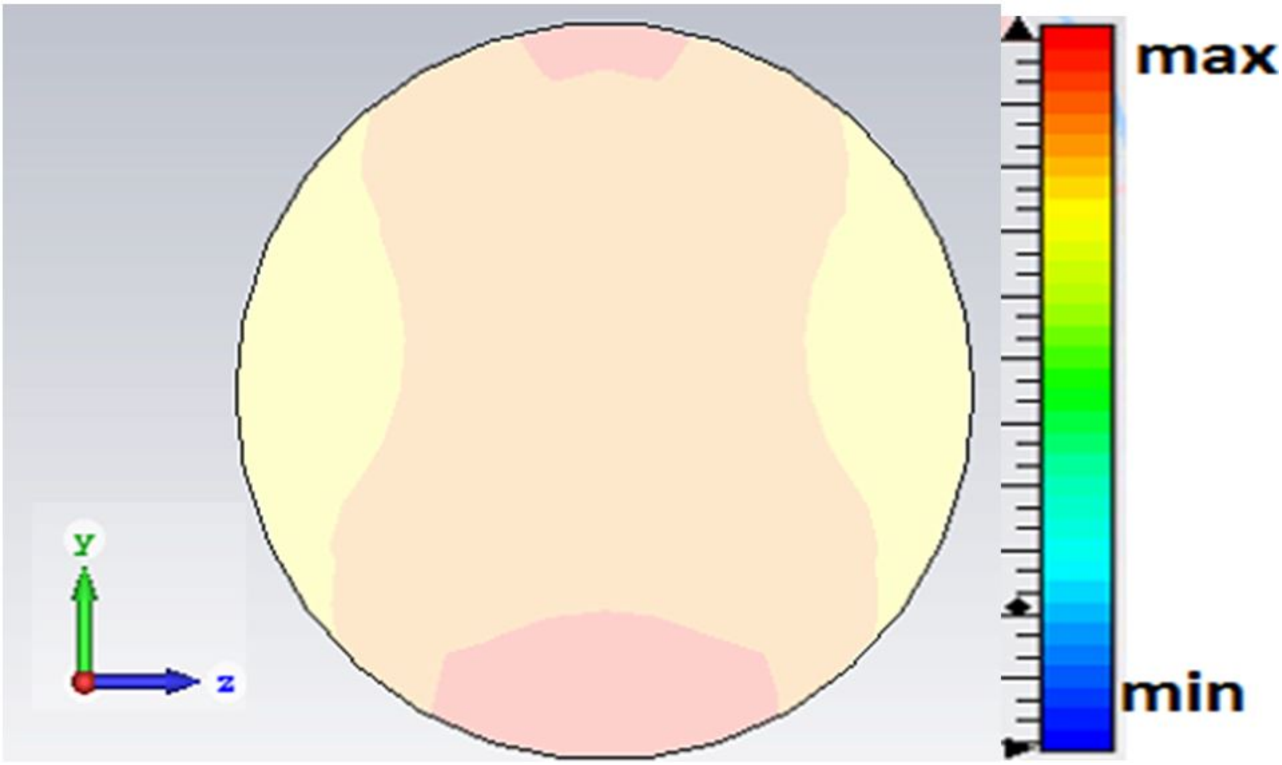
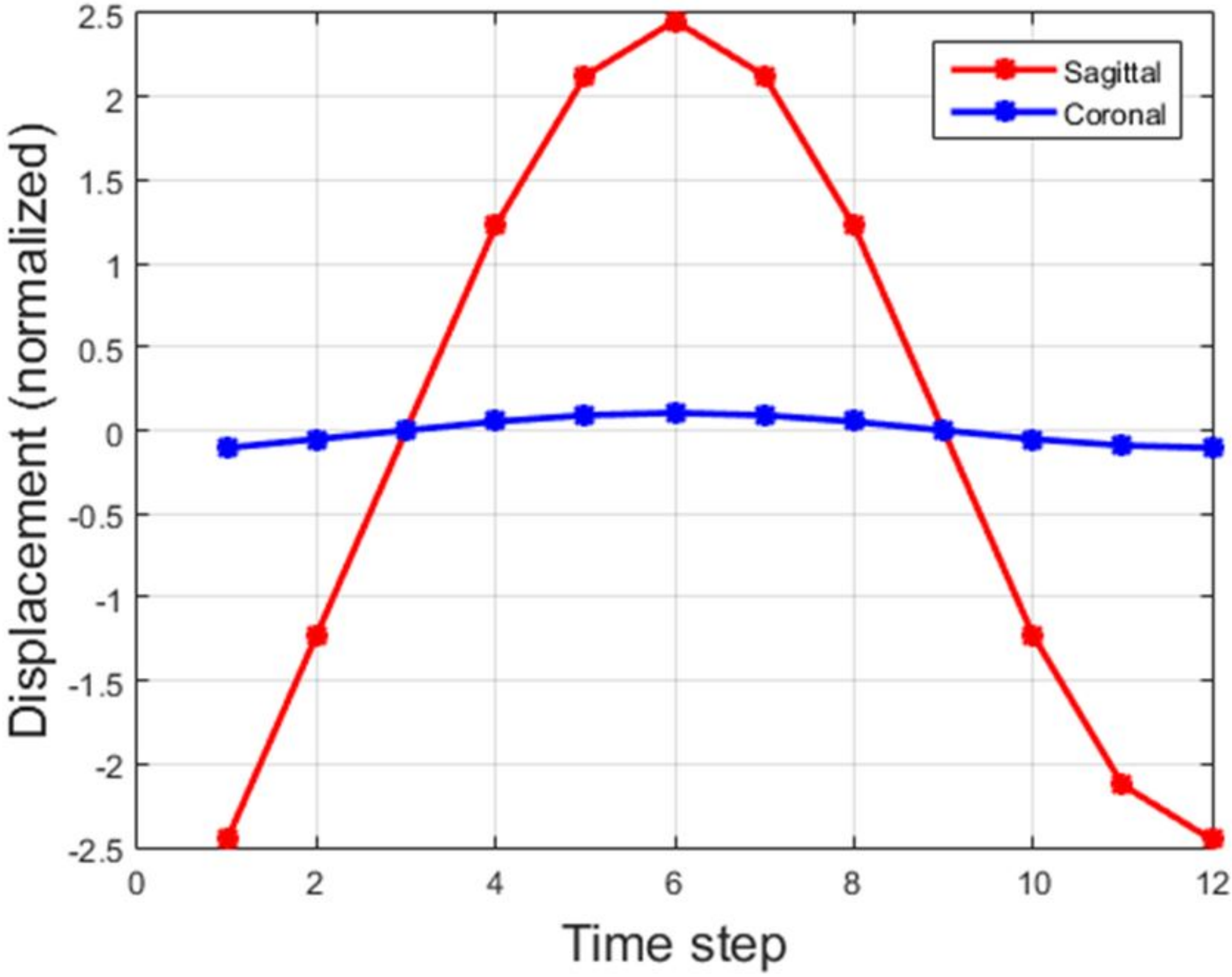


Fig. 3. Displacement over time step (normalized)


y
x
max
min


max
min
y
z


Sagittal
Coronal
Displacement (normalized)
Time step
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
2
4
6
8
10
12