Multi physics modeling of eddy current vibration damping in MRI systems

Kishore Venkata Mogatadakala[1], Ming Yao[1], Sampath Telikicherla Kandala[1], Longzhi Jiang[1], and Timothy Havens[1]
[1]*Magnet and Gradient engineering, GE Health care, Florence, SC, United States*

Introduction:

Vibration of MRI systems induces eddy currents in surrounding materials including thermal shield, helium vessel, etc. These eddy currents can generate main B0 field disturbances, which are detrimental to image quality (IQ) [1]. The vibration modes in low frequency (<50 Hz) regime are generally rigid body modes and are local deformations at high frequencies. Simulating these vibration induced eddy currents using analytical equations [2] provides insight for rigid body motion induced field disturbance at low frequency for MRI system. However, magnet cryostat gets extremely complicated locally deformed modes for high frequency. In current study, coupled structural and electromagnetic FEM equations are solved using COMSOL multi physics package to simulate the vibration induced eddy currents for both high and low frequency and B0 field disturbances.

Methods:

Coupled electromechanical finite element equations are given in Equations [1]-[4]. Where, $\mathbf{J}_{ext}$ is external current density applied, $\mathbf{B}_0$ is main static magnetic field, ρ is density of the material, $\omega = 2\pi f$, $\mathbf{u}$ is displacement, $\boldsymbol{\sigma}$ is stress, $\mathbf{F}_\mathrm{v}$ is applied body force, $\mathbf{J}_{eddy}$ is induced eddy current, $\mathbf{B}_{eddy}$ is field disturbance due to $\mathbf{J}_{eddy}$ and σ is electrical conductivity. The equations are solved using COMSOL multi physics software (ver. 4.a) by including AC/DC electromagnetic module and structural mechanics module. The term $\mathbf{J}_{eddy} \times \mathbf{B}_0$ in Eq. [2] introduces force due to eddy current and adds additional electromagnetic (EM) force that results in additional damping to the vibrating structure.

$$\nabla \times \mathbf{B}_0 = \mu_0 \mathbf{J}_{ext} \tag{1}$$

$$-\rho\omega^2\mathbf{u} - \nabla\cdot\boldsymbol{\sigma} = \mathbf{F}_\mathrm{v} + \mathbf{J}_{eddy} \times \mathbf{B}_0 \tag{2}$$

$$\left(j\omega\sigma - \omega^2\varepsilon_0\right)\mathbf{A} + \nabla\times\nabla\times\left(\mu_0^{-1}\mathbf{A}\right) = \mathbf{J}_{eddy} + \sigma(j\omega\mathbf{u}\times\mathbf{B}_0) \tag{3}$$

$$\nabla \times \mathbf{A} = \mathbf{B}_{eddy} \tag{4}$$

Results:

A simple aluminum sheet (AL 6063, 1 x 0.05 x 0.003 m) is modeled as a cantilever beam in a background magnetic field (Fig-1.A). 1N/m³ force is applied at one end and other end is fixed along z-axis (Fig-1.B). As shown in Fig-1.C, simulation has predicted resonance at 2.6 Hz with vibration attenuated by factor of 6 due to additional EM force. The cantilever beam was placed in the background magnetic field and experiment was conducted to verify the simulation. Measured data in Fig-1.D has resonance at 3.2 Hz with an attenuation factor of 7.

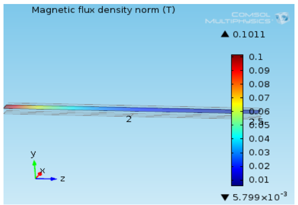

Figure 1.A: Cantilever beam in magnetic field

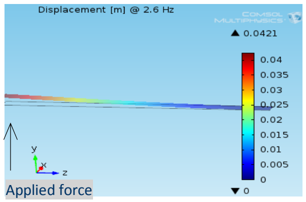

Figure 1.B: Cantilever beam in magnetic field

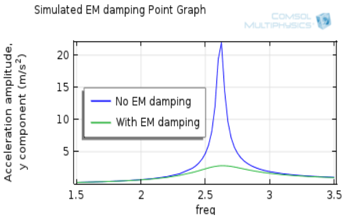

Figure 1.C: Simulation - Acceleration at the applied force end

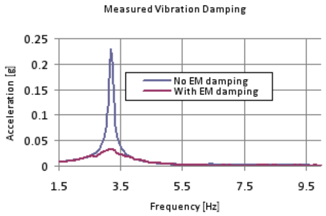

Figure 1.D: Measured acceleration

In order to demonstrate the application of this technique to more complicated resonance modes, a hollow cylinder (AL 6063, inner radius 0.65 m, outer 0.8 m, length 1m) is modeled in a strong magnetic field background (Fig-2.A). 1N/m³ force is applied as shown in Fig-2.B and corresponding shape deformations can be seen in Fig-2.B and Fig-2.C @ 164.6 Hz. From Fig-2.D and Fig-2.E, it can be observed that maximum field disturbance on a 25 cm DSV sphere has reduced from 6.1E-7[T] to 2.3E-7[T] due to EM damping.

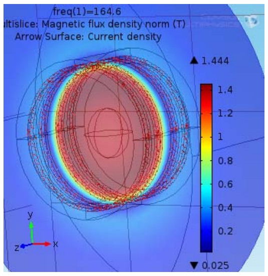

Figure - 2.A: Hollow cylinder in magnetic field

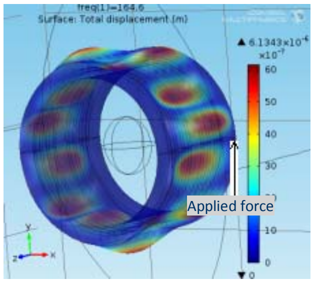

Figure - 2.B: Displacement with no EM damping

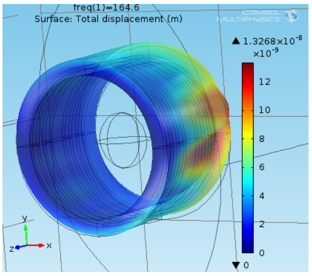

Figure - 2.C: Displacement with EM damping

Discussion:

Some imaging sequences (Fast spin-echo, EPI, etc) are extremely sensitive to B0 field disturbances and it is important to obtain NMR signals with phase consistencies between echoes. Otherwise, these phase errors can result in ghosting and ringing artifacts [1]. Simulating these B0 field disturbances for locally deforming modes at high frequencies is challenging. The coupled electromechanical FEM equations that are used in this study have demonstrated validity experimentally and can be used to simulate the B0 field disturbances due to any arbitrary resonance mode.

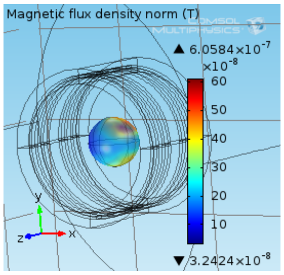

Figure - 2.D: Field disturbance on 25 cm DSV, No EM damping

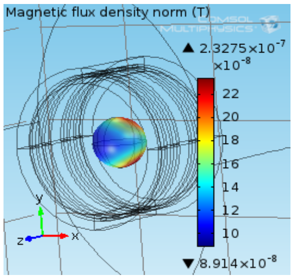

Figure - 2.E: Field disturbance on 25 cm DSV, with EM damping

References:

[1]: Mogatadakala KV, et. Al, Phase errors in FSE signals due to low frequency electromagnetic interference, Magn Reson Imaging. 2013 Oct;31(8):1384-9.
[2]: Jiang, Longzhi, et. Al, Environmental Vibration Induced Magnetic Field Disturbance in MRI Magnet, *Applied Superconductivity, IEEE Trans. on* 22.3 (2012)