Non-linear transient simulation of coupled acousto-magneto-mechanical systems in MRI scanners

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ABSTRACT

With recent advances in medical imaging techniques, Magnetic Resonance Imaging (MRI) has been at the forefront of development since the first patient scan in 1977. A need for early and accurate diagnosis of severe medical ailments, such as tumors, has made MRI a desirable imaging technique in the medical community. Most scanners generate a strong static magnetic field through a set of superconducting coils enclosed inside a set of highly conductive metallic radiation shields. Pulsed magnetic field gradients, excited through resistive coils inside the imaging volume, are used to generate an image. In the presence of time varying magnetic fields eddy currents and Lorentz forces are generated in the conducting components that cause them to deform and vibrate resulting in imaging artefacts (ghosting), decreased component life and generate pressure waves of the surrounding air that result in high noise levels for the patient.

In order to better understand these effects a linearised computational framework for the solution of acousto-magneto-mechanical coupling has been developed and presented in [1]. Here, the phenomena are described through the coupled set of Maxwell and linear elasticity equations. In the air the linear elasticity equations reduce to a scalar Helmholtz equation for acoustic pressure, and is coupled to the magneto-mechanical problem through magnetic source terms and interactions at the air-conductor interface. This work builds on [2], where we considered only the magneto-mechanical effects, a fixed point solution procedure and relied on a set of non-physical assumptions to present the system in the fourier (frequency) domain. Our new formulation presents a robust justification for the linearisation of the fields and uses a monolithic solution procedure. This scheme requires only one iteration to compute the solution, irrespective of frequency, whereas the fixed point scheme requires a number of iterations, which varies with frequency. The resolution of small skin depths, generated by eddy curents, and small acoustic wavelengths are vital to ensure accurate solutions are acheived. We use *hp* finite elements to accurately resolve these phenomena by applying a suitably high order interpolation of the fields. This approach has been rigorously justified by application to a series of benchmark problems, both academic and industrial.

However, these schemes rely on the temporal linearity of the fields which under certain circumstances of excitation are nonlinear in time. For instance, during an imaging sequence where the gradient fields represent pulsed trapezoidal waveforms, rather than that of sinusoidal harmonic excitations. Thus for these sequences we must solve the full transient system of coupled nonlinear equations, also presented in [1]. In this paper we present an extension to the current framework to include the time dependant formulation of the acousto-magneto-mechanical system. We will first benchmark the linearised temporal system against the linearised time harmonic system, before solving the full nonlinear temporal system in a predictive sense to analyse the response of a typical scanner during a simulated MRI scan procedure.

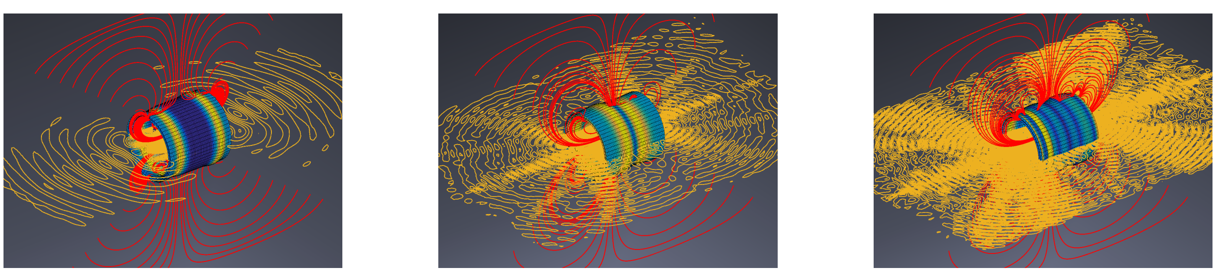

Figure 1: Simplified MRI scanner subject to time harmonic excitation: magnetic flux lines (red), acoustic contour lines (yellow) and displaced shields for different frequencies

REFERENCES

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