Application Sheet

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FEKO

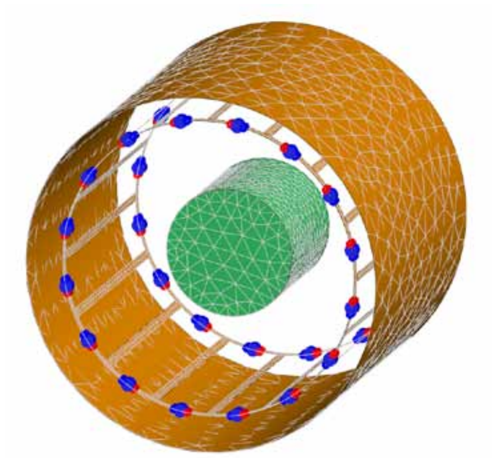
Comprehensive Electromagnetic Solutions

Electromagnetic and Thermal Analysis of a Human-Body Model with Implant in MRI

FEKO is used to ensure implant safety in MRI

Introduction

Image quality in magnetic resonance imaging (MRI) depends on good radio-frequency (RF) coil design. Such coils can be designed efficiently in FEKO thanks to the simulation methods the tool offers. Given well-designed RF coils, safety is still a concern, as RF power is absorbed by the body and causes local heating. This is especially the case when the patient has a medical implant since RF fields tend to concentrate around implant tips and can cause locally a high absorbed power and a relatively large temperature increase. This application sheet presents an example of a complete electromagnetic and thermal analysis.

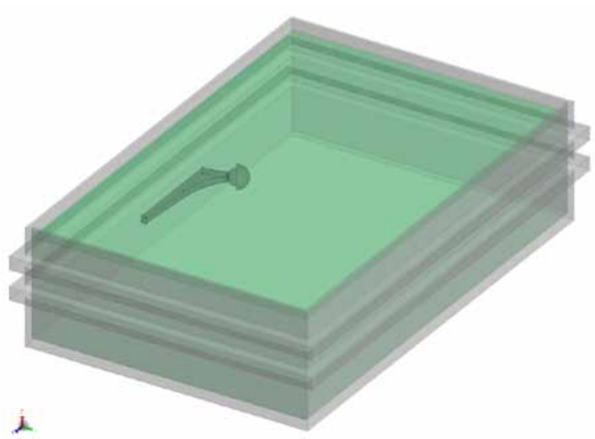


"Birdcage" coil with cylindrical phantom and shield

RF Coil Design

FEKO offers the proper simulation methods for efficient RF coil design. For a coil without a phantom, the central simulation method in FEKO, the method of moments (MoM), requires discretization of metal surfaces only, not the discretization of an air volume. For a coil with a phantom, one can either discretize the surface of the phantom and use MoM, or discretize the volume of the phantom and apply the hybrid finite element method (FEM) / MoM, depending on which approach is more efficient.

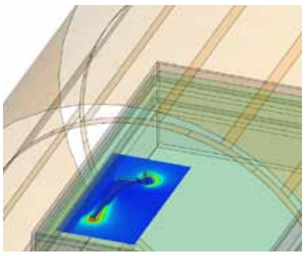
The top figure shows the MRI "birdcage" coil with a cylindrical phantom inside. The phantom is optional, but has been added to bring the coil closer to its actual operating mode. The system is fed in phase quadrature with two ports. After fixing geometrical parameters, among others coil radius (35 cm), number of rungs (16) and coil length (60 cm), capacitor values are optimized to bring the resonance with the rotating B field, known as the B_1+ field, to the desired frequency of 63.85 MHz for this 1.5 T system. The resonance frequency is the frequency where the imaginary part of the input impedance equals zero. In this case, this is achieved when all 32 capacitors have a capacitance of 47.27 pF.



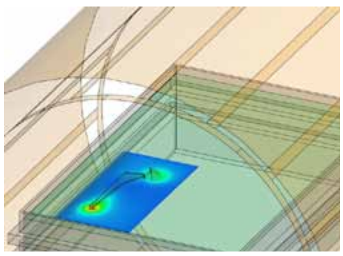
Hip implant in ASTM phantom

Implant in ASTM Model

Medical implants need to be tested for MRI safety in a controlled environment. This is commonly done by placing them in an ASTM phantom [1] and observing the temperature rise during an MRI scan. The middle figure shows a generic hip implant in the ASTM phantom. The phantom was placed in the MRI system. When the accepted power by the system equals 40 W, a level that is quite safe without the implant, the local specific absorption rate (SAR) is obtained, see figure to the right. Note how the presence of the metal implant leads to high SAR values near the tips.

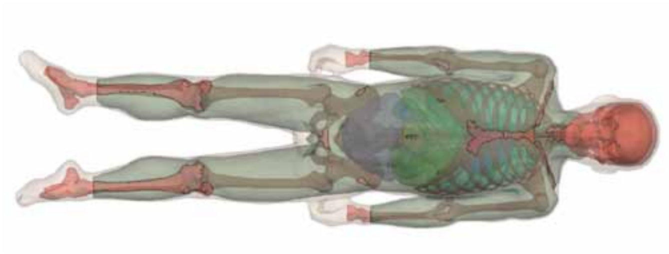


Local SAR distribution, linear scale 0 – 10 W/kg



Temperature distribution after 600 s, scale 293-295 K

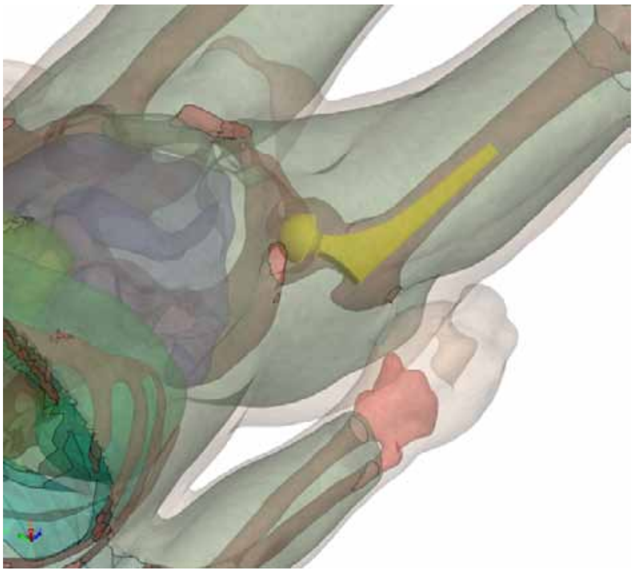
The scale is linear and ranges from zero (blue) to 10 W/kg (red). Knowing the absorbed power and the thermal material properties, one can calculate the temperature distribution as a function of time with a POSTFEKO script. All relevant thermal mechanisms can be included: power absorption, metabolic heat (zero in the phantom), thermal conductivity, air convection, thermal radiation, and temperature-dependent blood perfusion (zero in the phantom). The figure at the bottom of the previous page shows the temperature distribution after ten minutes.



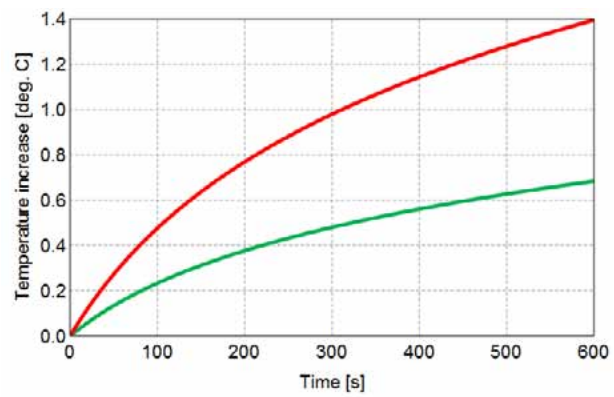
Human-body model from Simpleware, Ltd

Implant in Heterogeneous Human-Body Model

Although a simulation with a phantom approximates the test environment, a simulation with an inhomogeneous human-body model will reveal what will occur when an actual patient with an implant undergoes an MRI exam. Simpleware Ltd. [2] provides finite-element meshes of custom-designed human-body models. The figure at the top right shows the human-body model that was used in this study. A generic titanium hip implant was inserted into the mesh (right), after which the combination was remeshed for a finite difference time domain (FDTD) analysis. Like in the previous case, the SAR is large near the tips of the implant, but in this case the SAR also depends on the actual tissue: bone has a lower conductivity than muscle. The largest SAR occurred not in bone but in a muscle location close to a metal surface. The graph at the bottom shows the local temperature in this spot as a function of time for two power levels. In the thermal analysis, all thermal mechanisms were taken into account, including blood perfusion and metabolic heat. A power level of 40 W leads to a temperature increase larger than 1 deg. C, which is considered too much. A power level of 20 W keeps the temperature increase below this threshold, at least during the first ten minutes.



Hip implant in the Simpleware human-body model



Hot-spot temperature as a function of time at two different power levels: 40 W (red) and 20 W (green)

Conclusion

The simulation methods included in FEKO offer the "best of all worlds". MoM, which discretizes only surfaces, is efficient for MRI coil design, including when a phantom is present in the model. For complicated heterogeneous phantoms, the hybrid finite element method / method of moments (FEM/MoM) will be the fastest, while the finite difference time domain method will use the least memory.

References

[1] ASTM F2182-11a, Standard Test Method for Measurement of Radio Frequency Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging, ASTM International, West Conshohocken, PA, 2011, www.astm.org

[2] Simplware Ltd. http://www.simpleware.com/services/model-generation.html