SAR Safety Issues in Case of Partial Coil Loading

Peter Vernickel[1], Christoph Leussler[1], Daniel Wirtz[1], and Ingmar Graesslin[1]
[1]*Philips Research Laboratories, Hamburg, Germany*

Introduction

Rapid MR imaging requires an exact control of the specific absorption rate (SAR) to ensure patient safety while exploiting the allowed limits. Typically, SAR control is divided into two parts. First, the local and global SAR are predicted using a modeling software based on pre-calculated look-up tables or by online calculation of electromagnetic fields. Secondly, if the intended scan is within the limits, the applied RF signals are monitored before and during the scan using dedicated hard- and software. Doing this, i.e. measuring the complex coil currents I [1], coil quality factor Q, or reflection coefficient S_{xx} [2], allows to ensure the validity of the software model. In case the safe operating limits are violated the scan is aborted. However, uncertainties may exist when relying on the verification of one of the mentioned quantities, e.g. the coil current, because this can lead to ambiguous results when characterizing the complex arrangement of coil and load. As an example, the angle and the distance between a single coil element and an object surface are varied to demonstrate their heterogeneous impact on Q, I and the electric field E (SAR).

Methods

Using the software package FEKO (EM Software & Systems, Stellenbosch, South Africa), a set-up consisting of a single coil and cubic block was modeled (Fig. 1). The octagonal coil had a radius of the inner circle of $r_i = 65$ mm. The strip width of the copper path was 10 mm with four splits along the conductor intended for use of 0.38 " × 0.38 " type capacitors. The coil load consisted of a cubic dielectric block of the size 400 × 300 × 20 mm with a conductivity of $\sigma = 0.5$ S / m and a dielectric constant $\varepsilon_r = 80$. A thicker block does not lead to a remarkable change of the distribution of the electric field at the surface. The coil was placed in parallel with the surface of the block at an initial distance of d = 30 mm, and the initial rotation angle was $\alpha = 0°$. The coil was tuned and matched to the proton Larmor frequency of 3 T $f_L = 127.7$ MHz, and remained unchanged for the variation of d and α. In a first run, the angle was varied between $0° < \alpha < 20°$ (case 1), with the rotation axis parallel to the block surface such that one leg of the coil moved closer to the load, whereas the opposing leg moved away from it. In a second run, the coil as a whole was moved towards the load with -10 mm $< \delta d < 0$ and $\alpha = 0°$ (case 2). For each simulation run, the coil current I, the coil quality factor Q_L, the reflection coefficient S_{11} and the electric field E inside the load block were calculated. All relevant results were scaled to the reference magnetic field of $B_{1+} = 1$ µT at a reference point inside the loading block. To verify the simulation results, test measurements using an infrared (IR) camera (VarioCam, Infratec, Dresden, Germany) were carried out. The IR camera was placed to image the back of the loading block. Hydroxyethylcellulose (HEC) was used as a gelling agent to prevent convection inside the load. The magnitude of the RF power (200 W, block pulse, 5%) was set to a substantially larger value than required to achieve the reference B_{1+} so that heating in the phantom occurred without too strong heat conductance effects and within a reasonable test time (2 min RF heating).

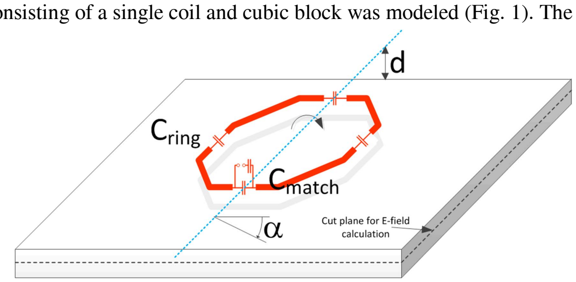

Fig. 1: Placement of coil (red) and load. The rotation axis is indicated in blue. The green layer indicates the plane for the E-field calculation.

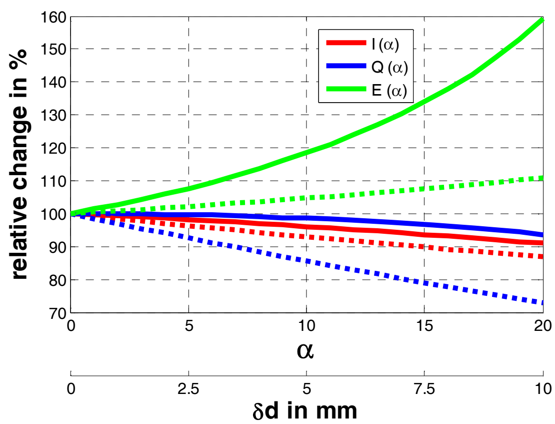

Fig. 2: Change (simulated) of the current, the quality factor Q, and the electric field E for variation of α (solid) and δd (dashed).

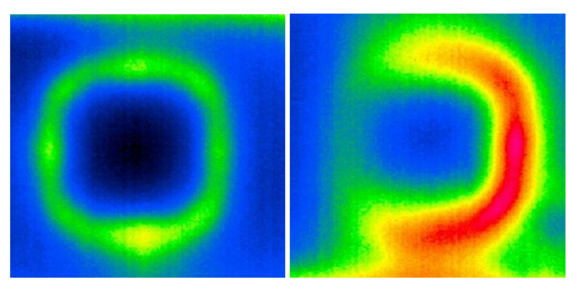

Fig. 3: IR camera images for the initial set-up (left) and for $\alpha = 20°$ (right). Temperature increase ranges from 0 -3 K.

Results

Initially, with four capacitors $C_{ring} = 34$ pF and $C_{match} = 29$ pF, the coil had a reflection coefficient $S_{11} = 0.002$ (-55dB), a quality factor $Q_L = 30.2$ and a current of I = 0.142 A for the required B_{1+}. Due to the change of the angle α (Fig. 2 solid), the quality factor changed to 28.3 and the reflection coefficient to 0.06 (-24.4 dB), and the magnitude of the current reduced to I = 0.13 A. While these quantities show a modest change, the E field increased by a factor of 1.6 in the region, where one of the legs got closer to the load. (Note: there were other areas with bigger increase, but those were not relevant due to a much lower initial level). Since, the E-field distribution was comparably flat, this resulted result in a remarkable increase of the averaged SAR_{10g} or SAR_{1g}. The opposite behavior was observed for the variation of the distance d (Fig. 2 dashed), where the quantities I, Q, and S_{11} showed a stronger change, whereas the impact on the field E was lower. The current reduced to I = 0.124 A, the quality factor decreased to $Q_L = 22$ and the reflection coefficient increased to $S_{11} = 0.16$ (-15.9 dB). However, the electric field only changed by a maximum factor of 1.11. When comparing the corresponding curves of the quantities which are typically measured with the simulation results of the electric fields, the problem becomes apparent. A measured drop of Q =30.2 to 28.3 meant in one case an increase the electric field by 1.6 (case 1: $\alpha = 20°$, $\delta d = 0$), but in the other case by a factor of 1.02 (case 2: $\alpha = 0$, $\delta d = 2.2$ mm). A similar behavior was observed for the coil current. A decrease of the current by 10% resulted in an increase of the electric field by a factor of 1.6 in one case (case 1: $\alpha = 20°$, $\delta d = 0$) and by a factor of 1.05 in the other (case 2: $\alpha = 0°$, $\delta d = 6.5$ mm). Evaluating also the phase of the current would lead to similar results. The overall pattern of the E field showed negligible dependence on the depth in the block. So, the calculated fields and the IR imaging results are qualitatively comparable. Fig. 3 shows the images made with IR the camera. The resulting temperature difference was 1.7 K for the initial set-up after and 3 K in case 1, the rotation of $\alpha = 20°$. The simulation results could be qualitatively confirmed, however heat exchange with the environment as well as thermal conductance, prevent a quantitative confirmation of the result.

Discussion

The expected heterogeneous dependence of Q, I and E on the geometrical arrangement was confirmed. It is clear that the calculated ratios are only valid for the set-up selected, but similar observations can be made for local transmit coils or whole body coils with different coil designs and channel count. This requires (a) to ensure a minimum distance between coil and patient by foam-padding or a thick enough and flexible coil housing, (b) sufficiently high safety margins during the SAR prediction, and (c) a careful placement of the coil and the patient. However, these measures come with the drawback of reduced coil efficiency, increased scan time, and increased effort for patient and coil positioning. More advanced methods for SAR control like (d) SAR determination via B_1 mapping [3] might help to overcome these drawbacks in the future.

References

[1] Graesslin I, Proc. ISMRM 14, 2006, 129; [2] Fontius U, Proc. ISMRM 14, 2006, 127;[3] Katscher U, IEEE TMI. 2009 Sep;28(9):1365-74