On the reduction of the transmit B1 non-uniformity and SAR using a single-element rotating RF coil

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Introduction Conventional RF technology struggles to provide safe, uniform B_1 fields for high-field MRI[1]. Additional tissue-heating, caused by field interactions and/or a RF energy misbalance, can be ameliorated by employing adequate numbers of arrays to tailor the fields. In this report, a new RF excitation technique has been proposed for compensating the B_1–field inhomogeneities while simultaneously controlling specific absorption rate (SAR). The method utilizes a rotating single-element coil[2] to emulate a large number of transmission coils/channels and then tailor both amplitudes and phases of the driving current of the rotating RF coil (RRFC). The advantages of this approach are that it obviates the need for multiple coils/channels and intricate RF decoupling of many coils, as well as offering adequate flexibility in the optimisation of the EM fields and thermal energy flows in the imaged object.

Methodology

Modelling the biologically loaded single-rung RF resonator In this work, an unshielded single-rung RRFC operating at 400MHz is used to transmit the RF pulses, while the distortion of the RF field by biological samples is modelled with a tissue-equivalent sphere phantom (for rat imaging). The coil-load model setup is illustrated in Fig.1. Following parameters were used for the spherical phantom: $R = 23mm$; $\sigma = 0.5Sm^{-1}$; $\varepsilon_r = 40$, $\rho = 1050\ kgm^{-3}$. The coil parameters: $R = 37.6mm$, length = $90mm$; rotating speed = $2000rpm$. A hybrid numerical technique, Dyadic Green's function/Method of Moment *(DGF/MoM)*[3], is used to model the coil-sphere interactions, and the SAR is computed based on the evaluated total E-fields. The EM fields produced by the single-rung rotating coil are modelled by a substantial number of decoupled coils evenly distributed around the sample. The phase-shift due to sequential motion is explicitly included into the harmonic field calculations.

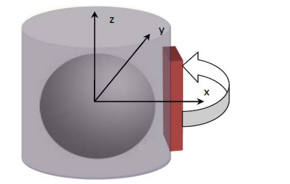

Fig.1 Schematic arrangement of a single-rung rotating RF coil adjacent to a homogenous spherical phantom.

Optimization method L_1-regularization technique[4] is employed to solve the ill-posed linear system equation and determine the rung currents at each angular position during RF pulse transmission. In the optimization procedure, the first step is to construct the discrete system of linear, complex algebraic equations $\mathbf{AI} = \mathbf{B}$, $\mathbf{A} \in C^{mn}$, $I \in C^n$, $B \in C^m$: each element $A(p,q)$, $p = 1, 2, \ldots, m$; $q = 1, 2, \ldots, n$ is the DGF evaluated B_1 -field $((Bx + iBy)/2)$ and E-field value generated by unit current in rung q (the continuous angular rotating is represented by a large number of discrete current elements) at field points p, **B** defines the target fields at the sampling positions over the entire imaging plane and **I** is the current source on each position of the rung. The second step is to solve the linear system equation using a constrained regularization algorithm[4] for the determination of the RF coil source profile **I,** which can offer improved uniformity of B_1-field and minimized SAR inside the sample.

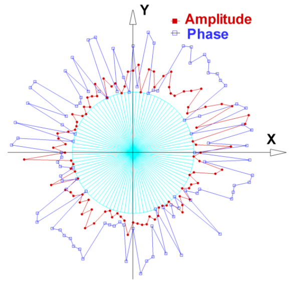

Fig.2 Optimized current profile (normalized to [0~1]. amplitude range: 0~0.33A; phase range: 0~360°.

Simulation To obtain the sensitivity profile of each rung current, 100 (adequate for this study) EM simulations were firstly carried out and each calculation took about 9.6*sec* on a 3 GHz PC. In the simulations, 4(*r*-)-by-13(*phi*-) uniformly distributed field points in the z = 0 plane were sampled with targeted B_1-field of (1+i) and E-fields corresponding to SAR=0.08*W/kg*. After this, the source profiles of the RRFC can be determined within 27*sec* by optimization. Fig.2 shows the optimized current profiles. It is noted that a large number of angular positions correspond to 'null' excitation, and hence the optimized RF excitation scheme will efficiently deliver the RF energy into the sample without excessive power deposition. Fig.3 shows comparative results in terms of B_1-fields and Fig.4 compares the obtained SAR values between the standard birdcage-mode excitation and optimized rotating excitation. The results indicate a notable improvement in RF homogeneity, i.e. about 95% of the B_1 -nonuniformity caused by loading effects can be compensated for by optimizing the driving of the rotating rungs. In terms of local SAR, it can be seen that all the "hot spots" have been removed from the entire imaging slice, and the peak SAR generated by the optimized current is more than 200 times smaller than that of a bird-cage type excitation.

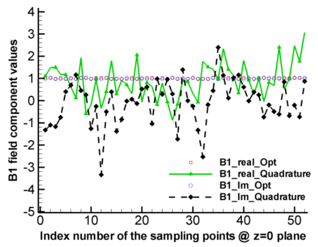

Fig.3 The comparison of the optimized and quadrature-excitation solutions of complex B_1-fields in the imaging plane.

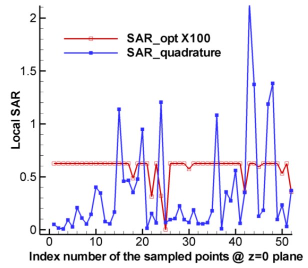

Fig.4 The comparison of the optimized and quadrature-excitation solutions of local SAR values in the imaging plane. (For plotting, the optimized SAR is enlarged by 100 times).

Discussion and conclusion

In this work, we have studied the RF field shimming technique using active control of source profiles of a biologically loaded one-element rotating volume coil. Compared with stationary, multi-array excitation techniques, the RRFC configuration offers an extremely large set (can be two or three orders more) degree of freedom for searching of optimal current source profiles. The generation of thousands of EM field sources is facilitated, making it an ideal EM field tailoring concept with capabilities beyond the current array technology. The simulation shows that inside a whole imaging area, B_1-inhomogeneity can be ameliorated substantially compared with the standard quadrature excitation. More importantly, the optimized rotating excitation technique can significantly mitigate the tissue heating. It is explained that the outperformance of the rotating exaction is mainly due to its capacity for the constructive generation of targeted EM fields; however, the quadrature drive lacks flexibility and produces a large amount of destructive RF contributions. The outstanding performance of the new RF transmitting technique as demonstrated in this primary study will require a further investigation and practical validation. The new driving scheme can also be easily applied for RF field focusing and human imaging: the increased flexibility combined with the adaptive patient model database allows us to relax both the dependency of electro-thermal tissue properties and body-coil geometries to perform robust, local SAR-optimised field focusing. It therefore has the capability to robustly achieve practical trade-off between field homogeneity and SAR. Together with receiving and imaging reconstruction methods[2], a further development of the RRFC technology might lead to an innovative RF solution for homogeneity issues with high-field MRI.

Reference

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