Reducing Short Term Gradient Heating by Usage of Adapted Encoding Schemes

P. Freitag[1]
[1]Bruker BioSpin MRI GmbH, Ettlingen, Germany

Introduction: Gradient overheating is one of the limiting factors for the performance of any MRI system. Gradient systems must be protected against slow overall heating as well as fast heating spots. These may not be detected by conventional temperature sensors but may cause irreversible damage to the insulation material. For this reason gradient supervisor hardware controls the short term average or filtered power dissipation (in the following abbreviated as STPD). Standard Fourier encoding methods use linear encoding schemes, which cause a non uniform distribution of the current heat dissipation during the experiment time. Especially for 3D methods, this will lead to STPD peaks when scanning the edges of the k-space thus limiting minimum field of view or minimum repetition time.

Method: Typical phase encoding schemes for Cartesian measurement methods are separable, i.e. the k-space is traversed line or column wise. These schemes allow easy and effective implementation on the scanner sequencer but causes STPD peaks in the edges of k-space. The actual STPD depends on properties of the gradient systems like cooling and coil geometry. In order to optimize the STPD, a model for the unfiltered power dissipation is needed which will allow a suitable weighting of the individual encoding steps. Typically a quadratic weighting $w(x_1,...,x_n) = w_1 x_1^2 + ... + w_2 x_n^2$ is appropriate for an n dimensional encoding with k-space coordinates $x_1,...,x_n$ and with hardware specific weighting factors $w_1,...,w_n$., as the power is quadratic with the k-space distance from center.

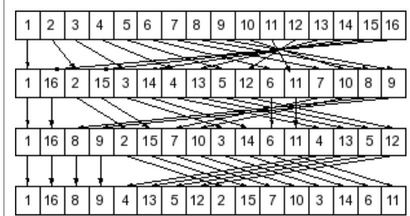

Fig 1: Reordering encoding steps

Starting with an arbitrary enumeration of the encoding steps $e_i = x_1(i),...,x_n(i), i = 1...N_{enc}$, the weights $W_i = w(e_i)$ of the encoding steps are calculated. Then the encoding steps are sorted such that $W_{\sigma(i)} \le W_{\sigma(i+1)}$ for all I, where σ is the sorting permutation. The Half of the components with lowest weight is reversed and shuffled with the entries of the the entries of heighest weight. The procedure is repeated doubling the size to be shuffled in each iteration up to a quarter of the total length. Figure 1 shows the iterated mixing process for 16 phase encoding steps. The effect of the rearrangement is displayed in the following figures. Figure 2 shows the power evolution of a standard Cartesian encoding scheme with a typical quadratic weighting function, Figure 4 shows the filtering over 50 averages. Figure 3 shows the power evolution after reordering according to the described algorithm, figure 5 shows the evolution after filtering. Here the filtered power evolution is approximately constant, which means that it is close to the optimum given by the total average.

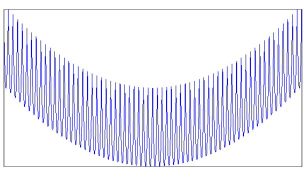
Fig 2: P vs. T :Unfiltered Cart.

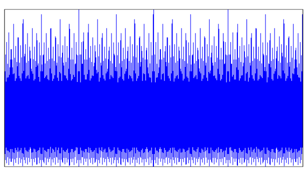
Fig 3: P vs. T: Unfiltered Reordered

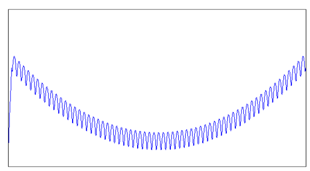
Fig 4: P vs T: Filtered Cartesian

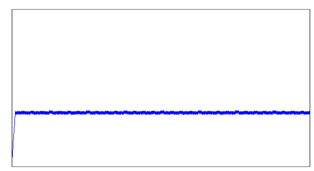
Fig 5: P vs T: Filtered Rearranged

Results: The expected gain of the STPD optimized encoding scheme is highest for methods where the phase encoding gradients are responsible for a large part of the total power dissipation. For this reason, the proposed encoding method was implemented for a 3D FLASH sequence on a Bruker BioSpec 7T small animal scanner. For short repetition times and small field of view, the STPD is dominated by the spatial phase encoding gradients. Calculation of the encoding scheme using a square weighted power dissipation model was fast enough to be integrated in the standard measuring setup for typical sizes like 256 cube. The expected STPD reduction was confirmed by the scanner built-in gradient supervisor unit, which controls STPD with a 1s window. For a 256^3 matrix, minimum TR was 13.4ms with a minimum (isotropic) FOV of 6mm without and 9.5ms with optimized encoding.

Discussion & Conclusion: STPD optimized encoding schemes allow the effective reduction of the STPD by up to 30% for fast 3D imaging sequences. When STPD is limiting sequence performance, appropriate encoding schemes allow a reduction of scan times by up to 20% depending on the measuring sequence. STPD optimized encoding schemes can be iteratively calculated with a complexity suitable for on the fly pre-scan calculation. They require however non separable gradient scheme descriptions which may drive the scanner sequencer capacities to its limits for larger encoding sizes.