SAFE-Model - A New Method for Predicting Peripheral Nerve Stimulations in MRI

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Introduction

Modern MR-scanners can have high performance gradient systems capable to switch gradients of 30 mT/m and more in less than 300 µs. At this level new physiologic limits are set for MRI by the appearance of peripheral nerve stimulations when the gradients fields are switched very fast (as an overview see [1]). Whereas the sensation the patient feels is very weak when the stimulation threshold is reached, the magnetostimulations can become uncomfortable and even intolerable when the threshold is exceeded by about 50 % and more [2, 3]. This shows the requirement of an adequate supervision to prevent the patient from stimulations but allowing the optimum use of the system performance.

New Stimulation Model

We have developed a new method to describe the dependence of the stimulation threshold on duration, waveform and number of the applied gradient pulses. This so-called SAFE-model (SAFE = Stimulation Approximation by Filtering and Evaluation) is schematically shown in Fig. 1. The model is empirical and was inspired by the physiological behavior of the nerve cells.

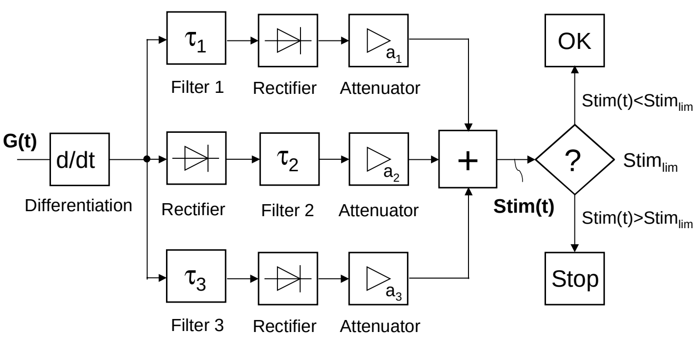

Figure 1. Schematic representation of the SAFE-model.

The gradient signal (*G(t)*) is first differentiated and then split to be processed with at least two lowpass filters described by their time constant τ_1 and τ_2. The use of a third filter branch is optional but normally gives better results. After filtering and rectification (respectively vice versa in filter branch #2) the signals are weighted with a scale factor (a_1, a_2, a_3) and summed to define the stimulation signal *Stim(t)*. If at any time *Stim(t)* exceeds a given limit $Stim_{lim}$ which is characteristic for the gradient coil, a stimulation is expected. The determination of the parameters of the SAFE-model is done by adjusting these parameters until the agreement of the calculated results with the experimentally found stimulation thresholds is accepted. Typical values are τ_1, τ_3 = 0.15..0.7 ms, τ_2 = 5..15 ms with $a_1+a_2+a_3 = 1.0$.

Results

Within a clinical study performed with 65 volunteers the stimulation thresholds in dependence of the duration of the gradient pulses were determined for the y-coil of a gradient system with gradient fields of up to 40 mT/m and a corresponding rise time of 0.2 ms. Both, trapezoidal and sinusoidal pulse trains consisting of 128 single pulses were used. The average value of the magnetic flux change at which the stimulation arises is plotted in Fig. 2 as a function of the duration of the gradient pulses. We prefer this representation introduced by Irnich [4] because then the values of the stimulation thresholds are fitted by a straight line and not by a hyperbolic curve when the stimulation thresholds are characterised in terms of dB/dt-values.

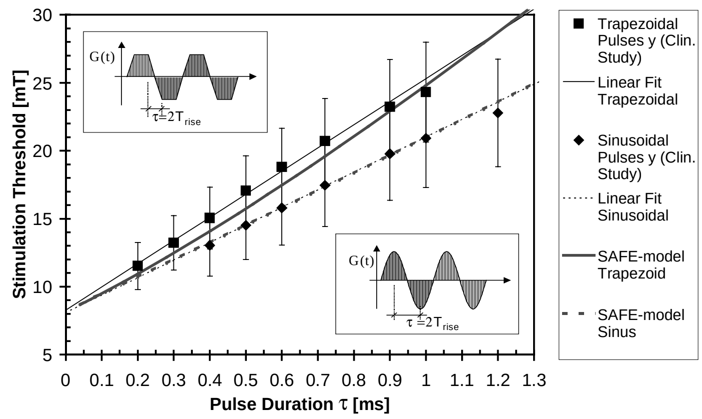

Figure 2. Comparison of the stimulus threshold for sinusoidal and trapezoidal pulses dependent on the rise time of the y-gradient pulses. The data of the clinical study is overlaid by the calculated values of the SAFE-model.

The whole set of experimental data collected within the study will be published elsewhere [5].

Discussion

The stimulation thresholds differ significantly when comparing trapezoidal with sinusoidal gradient pulses. This difference can be well described with the SAFE-model as can be seen in Fig. 2 where the SAFE-values are displayed as bold gray lines (dotted for Sinus). Regarding the sinusoidal pulses the calculated values show a perfect agreement with the linear fit of the experimental data with an average deviation of only –0.19 % between observed and modeled thresholds. The trapezoidal pulses also produce a good correlation, i.e. the calculated data describe nearly a straight line. In this case the SAFE-model is a little bit conservative so that the calculated stimulation thresholds for trapezoidal pulses are in average 4.2 % lower than the experimental ones.

The SAFE-model is able to predict with certainty the stimulation thresholds without an explicit knowledge of the gradient waveforms and rise times. It's therefore highly suitable to be implemented as a gradient dB/dt-watchdog.

References

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