Single Point Imaging with suppressed sound pressure levels through gradient-shape adjustment

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Abstract

SPI acoustic noise levels were modulated by means of changes in the spatial encoding gradients. We describe how to minimize noise levels by changes in gradient parameters. SPI with an optimized gradient waveform can be a superb alternative to the SPRITE method when sound levels and overheating of gradients are a concern.

Introduction

The Single Point Imaging (SPI) technique introduced by Emid and Creyghton [1] is extremely useful for imaging of samples with a very short transverse relaxation time. The SPI pulse sequence typically uses a very short time repetition of a few milliseconds and relatively strong gradients. This usually leads to excessive acoustic noise and sometimes even dangerous mechanical vibration of the gradient set. One possible approach to avoid these problems is the use of the SPRITE modification of SPI [2]. In the SPRITE sequence, gradient switching between consecutive phase encoding steps is minimized. However this "silent" sequence significantly increases the mean power deposition into the gradient system. This might in some cases, especially for not actively cooled gradients, cause overheating of the gradient coils. This makes it necessary to include cooling delays into the experiment to prevent damage due to overheating [3]. We propose an alternative approach that minimizes acoustic noise, gradient vibrations and overheating based on the optimization of the gradient waveforms.

Methods

The spatial encoding gradient pulse used in SPI will be characterized by the following parameters (see Fig.1): amplitude A, plateau length P, gradient ramp time R, time repetition T_R, and the actual ramp shape. Assuming that the applied phase encoding is a periodical and even function (*i.e.* neglecting the amplitude changes between successive phase encoding steps), the gradient waveform can be represented by a Fourier series. The non-zero frequencies of the gradients pulse spectrum can thus be calculated as Fourier coefficients a_n, which for a linear ramp are given by:

$$a_n = \frac{A(-1)^n}{\pi^2 n^2}\left(\frac{R}{T_R}\right)^{-1}\left[\cos\left(n\pi\frac{P}{T_R}\right)-\cos\left(n\pi\left(\frac{P}{T_R}+\frac{2R}{T_R}\right)\right)\right] \quad \text{for } n=1,2,\ldots \quad [1]$$

For a sine-shaped gradient ramp we obtained:

$$a_n = \frac{A(-1)^n}{\pi n}\left(1-4n^2\left(\frac{R}{T_R}\right)^2\right)^{-1}\left[\sin\left(n\pi\frac{P}{T_R}\right)+\sin\left(n\pi\left(\frac{P}{T_R}+\frac{2R}{T_R}\right)\right)\right] \quad \text{for } n=1,2,\ldots \quad [2]$$

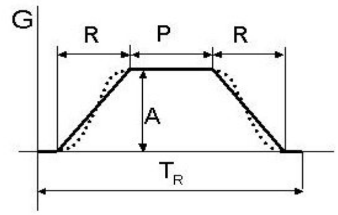

Fig.1 The gradient pulse shape used for phase encoding in SPI with linear and sine (dotted line) ramp.

It is well known that the frequency response function (FRF) of the gradient system usually exhibits a reduced response for (acoustic) frequencies below 200-600 Hz,which allows substantial suppression of mechanical vibration and acoustic noise if frequencies above this cut-off are minimized [4]. Optimization of the parameters R, P and/or gradient pulse shape was used to minimize the acoustic response. Figure 2, for example, shows the dependence of the total Power=10 log $\Sigma(a_n^2)$ on P and R, calculated (MatLab) for n=(2 to 99) (*i.e.* suppression of the first harmonics by the FRF is assumed) and T_R=4ms.

Results and Discussion

The SPI sequence with adjustable plateau length P, ramp duration R and choice of linear or sine ramp shape was implemented on an 11.7 T spectrometer equipped with a 72-mm self-shielded Magnex gradient system, SGRAD 123/72/S, and connected to a Bruker Avance DRX console. Acoustic noise levels were measured using a Bruel&Kjaer, 2238 Mediator sound level meter, equipped with a pre-polarized free-field condenser microphone type 4188 placed 20 cm deep into the magnet bore. FRF measurements (not shown here) indicated a reduced acoustic response below 750Hz. Sound pressure level (SPL) was measured for SPI using both linear and sine gradients with the following parameters: T_R=4 ms, P=256 µs, A=150 mT/m and R ranging from 0.175 to 1.6 ms. The results of the SPL measurements are shown in Fig.3. SPL showed a strong dependence on the gradient ramp length. When the physiological property of human hearing is taken into the account, *i.e.* using an A-weighted scale, the sinusoidal gradient shapes with longer ramps are preferable. The results proved that SPI, with optimized gradients parameters, could be an excellent alternative to the SPRITE method where overheating of gradients might be a concern. Figure 4 shows a typical SPI image of a jujube candy obtained with the sine-modulated gradients with: T_R=4ms, P=400µs, R=1ms, FOV=5x5x2.5 cm, 128x128x32 matrix and 35 min of acquisition time.

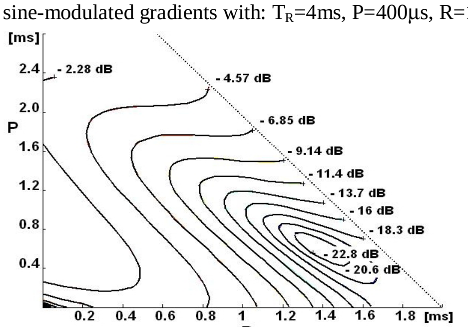

Fig.2 Spectrum power dependence of the gradient pulse on the R and P. The total power was calculated for Fourier coefficients a_n with n=(2 to 99).

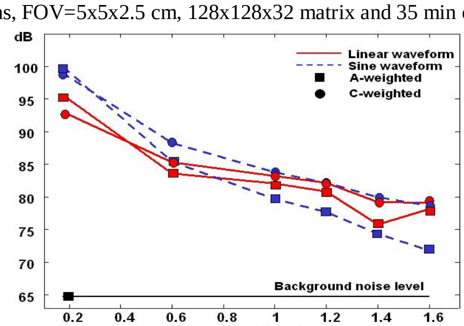

Fig.3 The measured intensities of SPL as a function of the ramp length and shape are shown in physiological A-scale and the C-scale.

Fig.4 Three-dimensional image of a jujube candy obtained by sine-modulated gradients.

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