Experimental Demonstration of nCPMG Realignment

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Introduction

Recently we described how a symmetry property of the *nCPMG* sequence could be used to create a perfect refocusing called realignment, to include also the z component part, at the end of the echo train (1, 2). The first experimental verification of this proposal was performed in the context of hyperpolarized 13C imaging, whereby longitudinal magnetization was retained from excitation to excitation (3). This experiment used a modulation which was specifically designed for realignment but was restricted to nutation angles above 160° (4). Last year we described a more effective preparation period permitting realignment of transverse magnetization with nutation angles as low as 130° (5) - but only simulation results were available. We present here the experimental results and more details of the phase modulation itself, in order to enable the easy reproduction of the experiment.

Theory

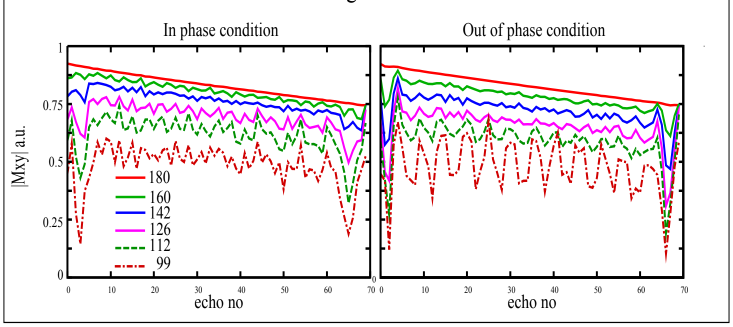
The preparation period of the *nCPMG* sequence, with P refocusing pulses, generates a rotation which has a special property, for any echo of index i≥P: it is symmetrical around a centre precession frequency $\Omega_c(i)=\delta(i)+\Delta/2-\pi/2$ [1] where $\delta(i)$ are the precession offset defining the modulation, and Δ the sweep rate used $\delta(i+1)-\delta(i)=\Delta$. This permits one to easily invert the sequence. If the preparation period $\{\delta(i), i=1..P\}$ gives a centre frequency $\Omega_c(P)=0$, it can be inverted by a sequence $\{\delta(j)=\pi-\delta_{2P+1-j}, j=P+1..2P\}$ [2]. If the centre frequency is not zero at the end of the preparation period, one can always come back to this case by subtracting the value $\Omega_c(P)$ from all $\delta(i)$. If the preparation period is followed by a linear precession of length L, it is still valid to consider this new sequence, of actual length L+P, as a preparation of length P' and use the equation [2] to invert the whole sequence. This becomes handy when given a sequence such as the one in (6) where there is no way to distinguish a preparation period and a linear sweep period. Starting from the emission phases X(i) and reception phases R(i), the $\delta(i)$ are recovered by $\delta(i)=R(i)-X(i)$; if the total number of echoes is N (with N=70 in the application below) we consider the first half P'= N/2 (=35) as a preparation sequence, obtain $\Omega_c(N/2)$ by equation [1](with $\Delta=1.2$), subtract this value from all $\delta(i)$, i=1..N/2 and finally use equation [2] to find the second half of the precession angles $\{\delta(j), j=36..70\}$. The result is summarized in Table 1.

Method

The sequence was tested on a GE Healthcare Signa HDxt 3T system, software release 15.0. The gradients of the sequence were similar to the ones used in imaging, but with the phase encoding turned off. The slice selection was in effect turned off also, by using a slice thickness of 160 mm whereas the phantom used was a glass test tube of 11mm diameter, 166mm long, its long axis along the z axis of the magnet and the acquisition performed at isocenter in a sagittal plane. The tube was filled just before the acquisition with tap water, with apparent $T_1=T_2$ in the order of 2.5s, and a recovery time of 10 seconds was used. The read direction was along z (long axis of the tube). Each echo signal was composed of 128 points, for a field of view of 24cm, with a bandwidth of 128 kHz (1000Hz/pixel). Each signal was Fourier transformed, in effect realizing a projection perpendicular to the long axis of the object. The magnitude of each reconstructed 1.86mm 'slab' was taken and the magnitude signal of a larger slab representing 50mm at the centre of the tube was obtained by summation. This yields a signal $|M_{xy}|$ for each of the echoes i=1,70. We repeated this acquisition for six nutation angles 180,160,142,126, 112, and 99 degrees. For each nutation we performed two acquisitions, the first with the initial magnetization at echo zero along x (in phase condition), and the second along y (out of phase condition).

RF no i	Table 1: nCPMG phase $\delta(i)$ in $2\pi.10^4$ radians
1..10	6634, 8328, 708, 2711, 3807, 5916, 8430, 309, 2022, 4049,
11..20	5501, 7607, 9332, 1444, 3201, 5203, 7301, 9110, 1098, 2941,
21..30	4974, 6845, 8632, 693, 2461, 4448, 6154, 8216, 80, 1957,
31..40	3894, 5846, 7800, 9648, 1545, 3455, 5351, 7199, 9153, 1105,
41..50	3042, 4919, 6783, 8845, 551, 2538, 4306, 6367, 8154, 25,
51..60	2058, 3901, 5889, 7698, 9796, 1798, 3555, 5667, 7392, 9498,
61..70	950, 2977, 4690, 6569, 9083, 1192, 2288, 4291, 6671, 8365.

Figure 1



Results

The signals are presented on Figure 1: one can observe an almost perfect rebuilding of magnetization during the last echo, the magnetization being within 1% of the maximum attained for 180°, for both initial conditions, and for nutation angles above 142°. Even at 126°, which is at the limit of the applicability of the preparation sequence, the last echo is within 3% of the maximum whereas the drop in signal is between 20 and 30%., when no realignment is tempted (not shown here).

References

(1) P. Le Roux, JMRE 155 p 278-292, 2002. (2) P. Le Roux et al. ESMRMB 2009 no 114. (3) Yi-Fen et al. ISMRM 2010 no 1015. (4) P. Le Roux, ISMRM 2009 p.2657. (5) P. Le Roux, ISMRM 2010 no.3035 . (6) P. Le Roux, ISMRM 2006, p.3368

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