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Apparent Longitudinal Relaxation of Mobile Spins in Thin, Periodically Excited Slices

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1. Introduction

NMR experiments involving thin excited slices are of interest both for conventional NMR imaging and for mechanically detected magnetic resonance. Especially in the latter case, the thickness of the excited slices may be well below 1 µm. In samples containing fast-diffusing liquid components such as water, the diffusive exchange of spin magnetization between the excited slice and its surroundings on the time scale of the NMR experiments plays a major role. In a recent experiment [1], we have studied the influence of the diffusion balance on the apparent longitudinal relaxation behaviour measured in a saturation-recovery experiment. The results of this study suggest that in a 1 µm slice with a Gaussian profile, the apparent longitudinal relaxation time of water may be as short as 0.87 ms.

Under the conditions of the experiment described above, the sample was allowed for full spin relaxation (with the well-known bulk relaxation time) between each run of the saturation-recover experiment. In an actual imaging experiment or even more so in mechanically detected NMR [2], we can expect much faster and periodic excitation cycles. Under these conditions, the diffusive magnetization balance between the excited slice and its surroundings needs considering excited magnetization from previous excitation cycles, too. This diffusional balance will also be dependent on the presence of diffusion barriers and relaxation sinks outside the excited slice.

2. Simulations and experimental approach

While the diffusion balance in a simple saturation-recovery experiment can be described in a straightforward analytical model, the diffusion balance in an experiment with periodic excitation is more complicated, especially if barriers and relaxation sinks are to be included into the treatment.

For this problem, a one-dimensional simulation model based on a spatially and temporally discretized diffusion equation along with bulk relaxation and surface relaxation was developed in which the NMR response after each excitation event in a pulse train is computed. This approach is not even limited to periodic excitation cycles.

Simulations were conducted for a range of different conditions ranging from periodical excitation of free water to geometries with asymmetric barrier and relaxation sink configurations. In each simulation, the inventory of excited magnetization in the sample and the amount of excitable magnetization inside the excited slice were determined as a function of time. Figure 1 gives an example for a simulation with free water. In the greyshade plot, the spatiotemporal spreading of excited magnetization in the sample can be seen, in the diagram the magnetization inventory and the available excitable magnetization in the slice are given.

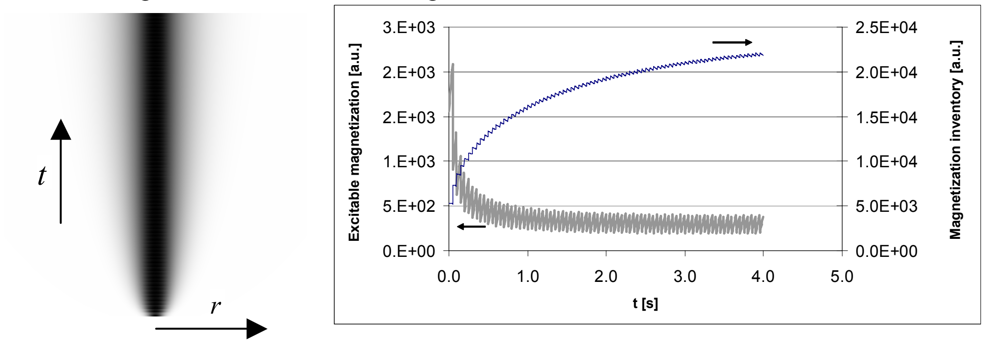

Fig. 1: Left side: Simulation of the spatiotemporal spreading of excited magnetization (grayshades) from a 30 µm slice of water (T_1 3 s) under the action of periodic 90° pulses applied every 50 ms. Right side: Development of the amount of excitable in-slice magnetization and and the overall inventory of excited nuclear magnetization present in the sample.

The NMR control hardware presently available on the specialized constant-gradient magnets at the TU Darmstadt which were also used in our previous experiments [1] did not allow the sufficiently flexible definition of multiple data acquisition windows necessary for studying the development of the excitable in-slice magnetization under the action of a periodic train of RF pulses. A new spectrometer control system and Software platform presently under development in our lab [3] will offer the necessary data acquisition options. Results from experiments taking advantage of these new experimental possibilities are expected till the conference.

3. Conclusion

In any slice-selective NMR experiment involving a slice with a thickness $s \leq \sqrt{DT_1}$, the diffusion balance between the excited slice may lead to changes in the apparent longitudinal relaxation time. Due to the buildup of an inventory of excited spin magnetization, the effect of diffusion on the apparent longitudinal relaxation is different for experiments involving periodic excitation. In those experiments, further modulations of the apparent longitudinal relaxation due to diffusion barriers and/or relaxation sinks on a length scale of s may occur, too.

References

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