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Dependence of NMR Signal Using Polarized Flowing Water on RF Field Amplitude

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I. Introduction

The nuclear magnetic resonance (NMR) technique using flowing water has been employed in the measurement of an average field over an extended path [1-3]. In this experiment, the water polarized in a high field passes through the RF field at one point and the resonance is detected at another downstream from the RF field. The NMR signal was affected by the arrangement of RF and detection coil on the flowing path and the average fields were measured between an RF and a detector coil [1], between the separated RF coils [2], or for the sphere volume [3] by utilizing the adequate arrangements of RF and detection coil.

The power delivered to the NMR detector during resonance transition using polarized flowing water has been analyzed in terms of the polarization and detection field [2], however, the phase change in NMR signal according to RF field is not available yet. In present work, the NMR experiment with a sphere on flowing path was performed with an RF and a detector coil in the measuring field down to the range of 0.1 mT and an attempt has been made to describe the change of the signal phase according to RF field.

II. Experimental Procedure

The NMR measurement system is available in the published paper [4]. In this system, the water flows through the tube of 4 mm inner diameter after polarization in a baffled chamber under 0.26 T, where the flowing water spends a time comparable to the longitudinal relaxation time. The polarized water flows into the 3 cm diameter sphere at the center of solenoid which is located in an earth's field compensated environment. The uniformity of solenoid field is about 5 ppm/cm using three auxiliary currents in addition to a main current.

Just before flowing into the sphere an RF coil of 0.33 mm length and 20 turns supplies a cw field oscillating at the Larmor frequency for protons in the measuring field. The RF field is fed from a synthesizer and the amplitude of this field is adjusted to optimize the resonance transition. A detector coil surrounding the sphere is orthogonal to both RF field and measuring field. The signal induced in the coil is detected by a lock-in amplifier. The detector coils have 800, 1600 and 3500 turns for the measurements of 1.0, 0.5 and 0.1 mT ranges respectively, and their signal-to-noise ratios are improved by tuning them at the Larmor frequency of measuring field.

III. Results and Discussion

The NMR absorption signals for RF amplitudes B_1 = 0.23, 0.49, 0.88 and 1.40 μT in the flow rate of 20 cm^3/s are shown in Fig. 1(a)-(d) respectively, where the amplitude of signal changes together with the signal sign equivalent to the 180° phase change. The phase of the signal changes periodically with an interval of 1.2 μT and the optimized RF amplitude is about

0.5 μT from the plot of NMR signal versus RF amplitude in Fig. 2. The change of signal amplitude is due to the sinusoidal variation of transition probability P with the increasing B_1 and its phase change is ascribed to the positive or negative sign of the signal according to the sign of the derivatives, dP/dB_1 [5]. The signal amplitude in polarized flowing water is given by the product of polarizing field B_p and measuring field B_o [5], and the high polarizing field offers a capability to obtain a good NMR signal even in the low field of 0.1 mT range.

In conclusion the periodic changes of signal amplitude and phase for the increasing RF field are ascribed to the sinusoidal variation in the resonance transition. The NMR signal with a good signal-to-noise ratio was demonstrated down to 0.1 mT range to determine the field within the uncertainty of a few tens per million.

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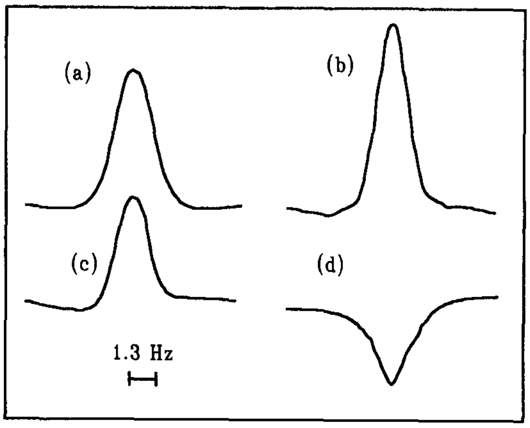

Fig. 1. NMR absorption signals measured for the different RF amplitudes (a) 0.23, (b) 0.49, (c) 0.88, and (d) 1.40 μT at water flow rate of 20 cm^3/s.

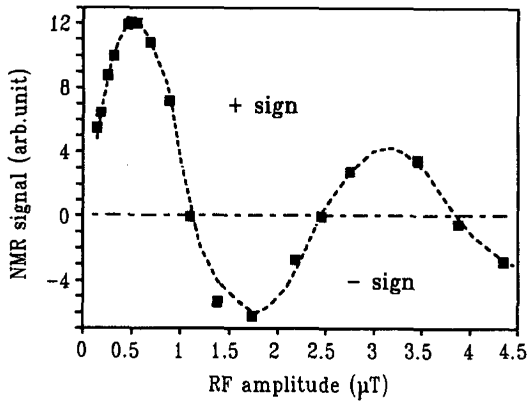

Fig. 2. Dependence of NMR signal on the RF amplitude.