Development of a Computer-Based Pulsed NMR Thermometer

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Abstract

We have designed a fully computer-controlled pulsed NMR system, using the National Instruments PCI-6115 data acquisition board. We use it for millikelvin thermometry and have developed a special control program, written in LabVIEW, for this purpose. It can perform measurements of temperature via the susceptibility or the τ_1 dependence. This system requires little hardware, which makes it very versatile, easily reproducible and customizable. The program is available from our website.

Key words: pulsed NMR; thermometry; platinum; millikelvin

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1. Introduction

Pulsed nuclear magnetic resonance (NMR) is a very important technique for measuring temperature in the millikelvin range and below [1]. It uses the Curie temperature dependence of the magnetic susceptibility of a paramagnetic sample, usually platinum (^{195}Pt). The measurement of this susceptibility is often made with pulsed NMR techniques at frequencies well below 1 MHz in order to minimize power dissipation in the sample.

Typical modern pulsed NMR systems use a collection of hardwired electronics, both analog and digital, as well as computer tools for analyzing the relevant signals. Since I/O data acquisition (DAQ) boards have increased in speed and power and since related software have made their use quite straightforward, we decided to replace as much analog electronics as possible with a computer and a DAQ board. The underlying idea was to make the apparatus more versatile and easy to replicate.

We have developed a control program, written in National Instruments LabVIEW. Temperature can be determined through measurement of the susceptibility, governed by the Curie law, or by measurement of the spin-lattice relaxation time τ_1, nominally governed by the Korringa law. It might also be useful for other NMR purposes. It is available, with hardware instructions and additional information, on our website [2].

2. Presentation

The hardware setup consists of $\mathbf{H}_0$ and $\mathbf{H}_1$ coils wound perpendicularly around the sample, a home-made analog electronics box containing a low-noise preamplifier and two solid-state relays, a DAQ board and a computer. The $\mathbf{H}_0$ coil provides a DC magnetic field. The $\mathbf{H}_1$ coil is part of a resonant circuit, and is used for both excitation and pickup of the induced response. The relays are used for isolating the preamplifier during the excitation and to quench the remaining current in the $\mathbf{H}_1$ resonant circuit after the excitation. The setup will be described in detail in the forthcoming paper.

One LabVIEW module (M) performs a single NMR pulse. The computer instructs the board to generate the excitation and timing signals and to record the response of the sample. An example of those signals is displayed in Fig. 1. Higher-level modules use the

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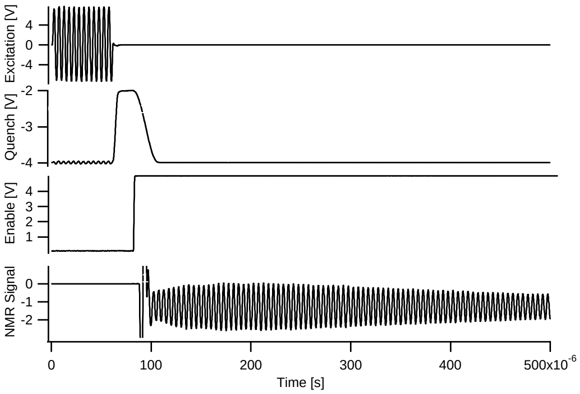

Fig. 1. An example of the signals handled by the computer. The second one (*Quench*) kills the remaining current in the $\mathbf{H}_1$ resonant circuit after excitation. The third one (*Enable*) controls switching before the preamplifier. The first two signals can be shaped at will. The timing between them is controlled with 0.1 μs precision.

M module to perform various measurements, such as susceptibility or τ_1. These modules pass parameters to M, then process and save the data returned by M. The architecture of the program is open, which lets users build their own modules if wanted.

The board we use is the National Instruments PCI-6115. It allows one to update two analog output channels at 2.5 MSamples/s each and to record up to 16 MSamples at 10 MSamples/s with 12-bit resolution [3].

The program lets the user choose the excitation frequency, amplitude, and length, as well as parameters for the timing and the response recording. It measures the amplitude of the response by integrating the Fourier transform around the Larmor frequency. The integral is proportional to the sample magnetization, assuming τ_2^* is temperature independent, which seems to be true for ^{195}Pt at low temperatures [4]. τ_2^* is the decay time of the NMR signal, which arises from the dephasing of the nuclear spins due to the inhomogeneity of the applied field.

The program can also measure τ_1 by recording the recovery of the magnetization. This is done by giving pairs of large pulses separated with variable time delays, or a large pulse followed by a sequence of small ones separated by a fraction of τ_1. The option is given to convert τ_1 into temperature, yet one has to be aware of the large deviations from the Korringa law [5]. This measurement can be repeated automatically.

The tip angle curve (i.e. amplitude of the response as a function of the length of the excitation) can be recorded automatically. The user specifies the parameters for the excitation pulses, and the waiting time between measurements.

The program includes a file handling system. All the acquired graphs are saved if desired, and the measurement parameters are included in the files. Another module can re-analyze a series of previously recorded data files.

The computerization does not introduce any extra noise or heating of the sample. We have compared the signal to noise ratio (S/N) of this computer-based system to that of a home-made analog pulsed NMR system. For ^{195}Pt susceptibility measured near 5 mK the S/N of the computer system was lower by a factor of two. The main disadvantage is the sensitivity of this device to electromagnetic radiation from computer monitors and fluorescent lights, which is often reported with DAQ board systems.

We plan on building new modules, that will be able to output an arbitrary sequence of pulses, and to make the program able to perform automatically a given sequence of measurements. These will be used to implement other NMR techniques, such as spin echo measurements.

Acknowledgements

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