Tests of Modulated Intensity Small Angle Scattering in time of flight mode

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Abstract

We report results of tests of the MISANS technique at the CG-1D beamline at High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory (ORNL). A chopper at 40 Hz simulated a pulsed neutron source at the beamline. A compact turn-key MISANS module operating with the pulsed beam was installed and a well characterised MnSi sample was tested. The feasibility of application of high magnetic fields at the sample position was also explored. These tests demonstrate the great potential of this technique, in particular for examining magnetic and depolarizing samples, under extreme sample environments at pulsed sources, such as the Spallation Neutron Source (SNS) or the planned European Spallation Source (ESS).

Keywords: MIEZE, spin echo, HFIR, MISANS, ESS

1. Introduction

MISANS, MIEZE (Modulation of Intensity with Zero Effort) in the Small Angle Neutron Scattering (SANS) geometry is a rather new technique to probe quasi-elastic scattering with extremely high energy resolution. The method is well understood\textsuperscript{[1, 2, 3]} and efforts are under way\textsuperscript{[4, 5]} to establish the technique as a standard tool for measurements of slow dynamics.

The general trend of new neutron sources to be accelerator driven and thus to provide pulsed neutron beams raises the question how MISANS will perform in a pulsed mode. In earlier experiments the feasibility of MISANS on pulsed sources was demonstrated\textsuperscript{[6, 7]}, however these tests were only using the direct beam and relative low MIEZE frequencies.

The goal of this experiment was to show that a MIEZE can be set up easily at a new beamline and works well in the time-of-flight mode with samples. Therefore a compact turn-key MISANS setup from the FRM II in Munich\textsuperscript{[4]} was installed at the HFIR in Oak Ridge, Tennessee, USA, at the beamline CG-1D\textsuperscript{[8]}.

2. Setup of the Experiment

The used setup is shown in Figure 1: Two sets of MIEZE coils inside \(\mu\)-metal shielding\textsuperscript{[9, 4]} are placed between two polarizers. The polarizers are polarising solid state benders\textsuperscript{[10]}, which polarise the transmitted beam, but keep the collimation intact\textsuperscript{[11]}. We used two approximately \(10 \times 10 \text{mm}^2\) apertures (A\textsubscript{1} and A\textsubscript{3} in Figure 1) in about 3 m distance from each other for a rough collimation and suppression of the reflected spin states from the polarizers. The frequencies in the RF coils ranged between 46 and 149 kHz and matched the static fields:

\[ \omega = 2\pi f = \gamma B \quad \text{with} \quad \gamma = 2\pi \cdot 2.913 \text{kHz/G}. \]  

(1)

In order to simplify the setup, the coupling coils were replaced by small guide fields and therefore all static fields were either parallel or anti-parallel to the strong magnetisation fields of the polarizers. This simplification of the setup removed the need for an adiabatic rotation of the neutron polarisation in the static fields by 90\(^\circ\) as usual in MIEZE experiments and thus al-

\begin{figure}
\centering
\includegraphics[width=\textwidth]{setup.png}
\caption{Sketch of the setup used for the MISANS experiment during the second beam session, viewed from the side. The chopper (Ch) provided a pulsed beam with a frequency of 40 Hz and a pulse length of 0.14 ms, corresponding to a chopper opening of 2\(^{\circ}\). The two polarizers (P\textsubscript{1} and P\textsubscript{2}) were placed before and after the zero field region (hatched) of the MIEZE box, which contained the two MIEZE coils (C\textsubscript{1} and C\textsubscript{2}). Three apertures (A\textsubscript{1} to A\textsubscript{3}) were installed so that the beam is restricted to the sample (S), located inside a cryomagnet. The time-resolved detector (D) was placed at the correct distance to fulfill the MIEZE condition (eq. 3).}
\end{figure}
allowed a quicker adjustment of the setup in a new environment. The trade-off is that the MIEZE coils can only be operated in a $\pi/2$-mode, since the initial polarization is parallel to the static field of the $B_0$ coils. In this mode, each MIEZE coil must perform a $\pi/2$ flip to achieve the coherent splitting of two spin states that leads to the focused coherent overlap at the MIEZE point [12].

In contrast, in the usual MIEZE setup, which is preferred for all new developments, each MIEZE coil induces a $\pi$ flip, and in combination with a “bootstrap” arrangement a factor of four in time resolution is gained in comparison to our $\pi/2$ mode setup.

For this time-of-flight MIEZE instrument, the RF amplitude needs to be modulated to match the condition

$$\gamma B \frac{l}{v} = \frac{\pi}{2} \Rightarrow B(\lambda) = \frac{\pi h}{2m_\alpha \gamma l \lambda},$$

where $h$ is Planck’s constant, $l$ is the RF coil thickness, $v$ the neutron velocity, $m_\alpha$ its mass and $\lambda$ its wavelength. In a time-of-flight instrument, the wavelength of a neutron with time of flight $t$ at one component is given by $\lambda = \hbar t/m_\alpha \gamma l x$, where $x$ is the component’s distance from the source. As the MIEZE module was originally developed for operation at a reactor source, the RF current was not modulated with the time of flight in the present setup.

As detector we used a circular multi-channel-plate prototype [13], with a diameter of 40 mm and only about 15–20% detection efficiency for cold neutrons, but it provided sufficient time resolution and a very good spatial resolution (pixel size about 10 µm), both of which might become very useful in future tests at higher time resolution. The detector was always positioned according to the MIEZE condition

$$L_2 = \frac{L_1}{f_2/f_1 - 1},$$

where $L_1$ is the distance between the coils, $L_2$ the distance between second coil and detector and $f_1$ are the RF frequencies.

The chopper at CG-1D has an opening of $2^\circ$ and was running at 40 Hz, which results in a pulse length of 0.14 ms. At the first MIEZE coil, positioned 0.6 m from the chopper, this amounts to a wavelength spread of $\Delta \lambda/\lambda \approx 15\%$ at $\lambda = 3.5$ Å and 8 % at $\lambda = 6.5$ Å. At the detector position at 5.07 m distance, the $\Delta \lambda/\lambda$ reduced to 1.7 % and 0.9 %, respectively.

3. Results

We report the results from two separate beam sessions, where we implemented slightly different instrumental parameters. The goal in the first beam session was to set up the MIEZE devices for the first time at CG-1D, while the goal in the second beam session was to perform a first sample measurement.

3.1. First session

Figure 2 shows the result of the first test, a MIEZE modulation on the time-of-flight spectrum of the chopped beam at CG-1D with two different frequencies. The absorption edges of aluminum (marked with black arrows) and silicon (used in the solid-state polarizers) are clearly visible as dips in the Maxwellian shape of the spectra and were used to calibrate the time-of-flight to wavelength conversion. The RF frequencies were 46/69 kHz and 99/149 kHz, respectively, with distances $L_1 = 0.9$ m and $L_2 = 1.8$ m to fulfill the MIEZE condition. For calculating the MIEZE contrast in these and all other spectra, the spectrum is binned into 8 bins per MIEZE oscillation. Each oscillation spans a time-of-flight interval $t = 1/\Delta f$. To improve statistics, 8 to 15 individual oscillations are summed before a sinusoidal signal

$$I(n) = B + A \sin\left(\frac{2\pi}{\Delta f} n + \varphi\right) \quad \text{with} \quad n = 1, \ldots, 8$$

with a fixed phase $\varphi$ is fitted to the spectra. The contrast $A/B$ of the fitted signal is the MIEZE contrast. The maximum contrast in our tests was about 50 %, which is most likely due to one of the MIEZE-coil sets having been damaged during the overseas transport causing static stray fields near the RF-coils and therefore interfering with the correct operation of the flippers.

Note that for $\Delta f = 50$ kHz, the effect of not ramping the RF current becomes clearly visible: the $\pi/2$ flip is achieved for neutrons of 3 Å, which means that at the same current neutrons of 6 Å will be flipped by $\pi$, which makes the contrast vanish.
completely in our MIEZE mode. If there was enough intensity at 9 Å, one should see a considerable contrast again, in this case making $3\pi/2$ flips in the coils.

### 3.2. Second session

All the following measurements were performed in a second beam time, using only one set of RF frequencies of 99/124 kHz. The frequency ratio was chosen differently because with eq. (3) it results in a longer distance between second coil and detector, and allowed us to insert a cryomagnet at the sample position.

To elucidate the effect of RF current ramping, figure 3 shows the contrast as a function of wavelength in the direct beam for various output voltages applied at the RF generator. The solid lines are guides to the eye. The MIEZE frequency was $\Delta f = 25$ kHz. Note that with eq. (2) half the RF field should flip twice the wavelength; this does not hold for the output voltage due to nonlinearities in the RF amplifier and circuit.

![Figure 3: Contrast as a function of wavelength in the direct beam for various output voltages](image)

To obtain the intermediate scattering function $S(q, \tau)$, shown as the black curve in Figure 5, this data was normalized to the contrast measured analogously at $T = 27.55$ K at the Bragg peak at $q = 0.035$ Å$^{-1}$ for different spin-echo times, corresponding to different wavelengths in the incoming beam according to

$$
\tau_{\text{MIEZE}} = \frac{m^2}{\hbar^2} \Delta f L_S q^3,
$$

with the sample–detector distance $L_S = 1.035$ m.

For the data analysis, the part of the direct beam still visible on the detector has been subtracted in the form of a measurement at high temperatures, where no magnetic signal is present. The blue curve in Figure 5 shows the contrast measured in the neutron beam scattered by the MnSi sample at $T = 27.55$ K at the Bragg peak at $q = 0.035$ Å$^{-1}$ for different spin-echo times, corresponding to different wavelengths in the incoming beam.

![Figure 4: Intensity of the magnetic MnSi peaks as a function of position on the detector for various wavelengths](image)
Figure 5: The intermediate scattering function $S(q, \tau)$ of the MIEZE signal from MnSi at $q = 0.035 \, \text{Å}^{-1}$ is shown for $T = 27.55 \, \text{K}$ as measured (blue) and after normalization (black) with the instrumental resolution function as determined at $T = 2 \, \text{K}$ (green). The spin-echo times are calculated according to eq. (6).

4. Concluding Remarks

The effort to establish MISANS as a measurement technique for TOF applications is on the way and this paper documents important results along the path: the experiment establishes that MISANS can measure samples on pulsed neutron beamlines and the measurement of a MIEZE-signal in the direct beam with a 1 T horizontal field at the sample region demonstrates that this is a most promising technique for measurements of slow dynamics in high magnetic fields.

In the future, the setup could be extended to develop a MIEZE insert available as a standard option at several instruments at the SNS or at a dedicated MIEZE-SANS instrument at HFIR. It is also planned to propose a MISANS-type instrument for the European Spallation Source (ESS). Here, the instrument can benefit from the extended wavelength range, since the relaxed requirements on wavelength resolution typical for SANS are also acceptable for MIEZE-SANS. This means that similar gain factors can be expected.

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