New neutron radiography using oscillating intensity with MIEZE method for periodically moving objects

Mizuki Iriyama[1], Seiji Tasaki[1], Yudai Takita[1]
Kyoto University[1]

Introduction

What is a Neutron Spin Interferometer?

In a neutron spin interferometry, the neutron is split and superposed in spin state, enabling the observation of phase differences between spin eigenstates through interference.

Neutron spin interference is used to probe spinor properties, phase shifts, and quantum coherence in magnetic field environments[1].

What is the MIEZE method?

Modulated IntEnsity by Zero Effort, MIEZE[2], method is a type of neutron spin echo method, consisting of a spin polarizer, two resonance spin flippers (RSFs) and a spin analyzer and generates time-oscillating polarized neutron beam(time beat).

The oscillation frequency is equal to the difference between the frequencies of the two RSF π/2 flippers[Fig.1,2].

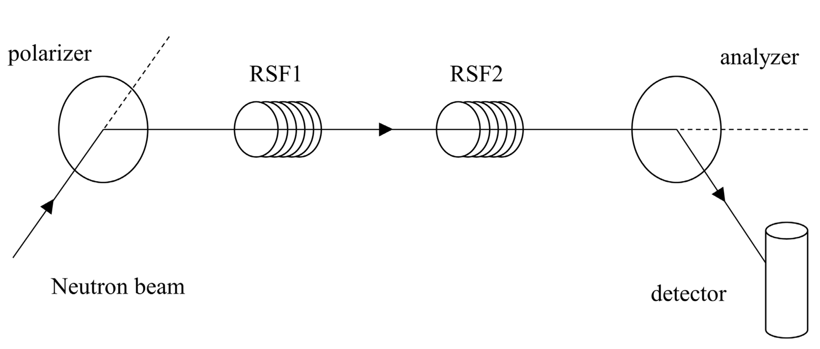

Fig.1 Neutron spin interferometer with RSFs.

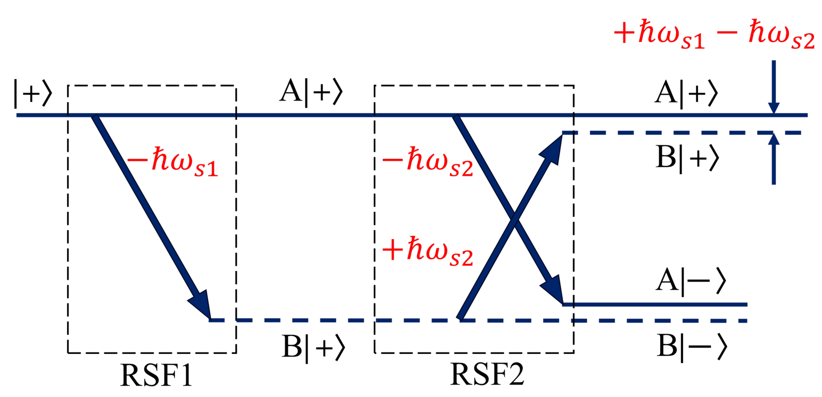

Fig.2 Spin and energy state transition diagram in the MIEZE method.

Quantitative expression of the time beat

The probability density of neutrons reflected by the analyzer mirror is given by the following equation[3]:

$$|\psi_{ref}|^2 = \frac{1}{2}\{1-\cos[(\omega_{s2}-\omega_{s1})(t-t_0)+(\chi_2-\chi_1)+\phi(\lambda)]\}$$

ω_{s1}, ω_{s2}: the frequency of RSF1, RSF2[Hz], χ_1, χ_2 : the phase of RSF1, RSF2,
t_0: the time of flight from RSF2 to the detector[s],
$\phi(\lambda)$: the dispersive phase depending on a neutron wavelength

The oscillating frequency of neutron beam is determined by the difference of the frequencies of the two RF π/2 flippers. Fig.3 shows an example of Low-frequency time beat, where the accuracy of the period (1000s) and the high visibility of the signal (over 0.95) is clearly observed.

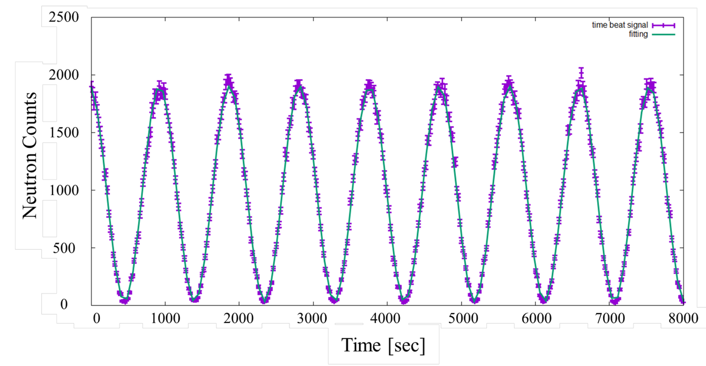

Fig.3 Time-oscillating pattern with a period of 1000 sec.

Objective

The objective of this study is to demonstrate the application of MIEZE method to neutron radiography, which gives us the Fourier component of a periodically moving object in accordance with the MIEZE frequency.

Material and Methods

Experimental Setup

- Neutron source

In this study, experiments were conducted at the C3-1-2-2(MINE1) beam line of JRR-3 reactor[Fig.4].

- Monochromatized as 8.8Å
- resolution 3.5%

Fig.4 MINE1 in JRR-3.

- Sample

- The sample is a fan composed of 11 plastic blades, with Cd partially attached to the surface of some blades[Fig.5].
- The fan can be operated in two rotation modes: a high-speed mode [17 Hz] and a low-speed mode [13 Hz].
- An optical sensor emits a trigger pulse once per fan rotation, initiating a fixed-duration current through the spin flippers that generates the MIEZE signal.

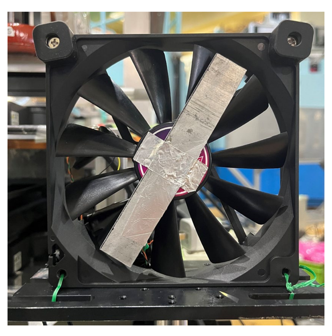

Fig.5 The sample fan.

Experimental Procedure

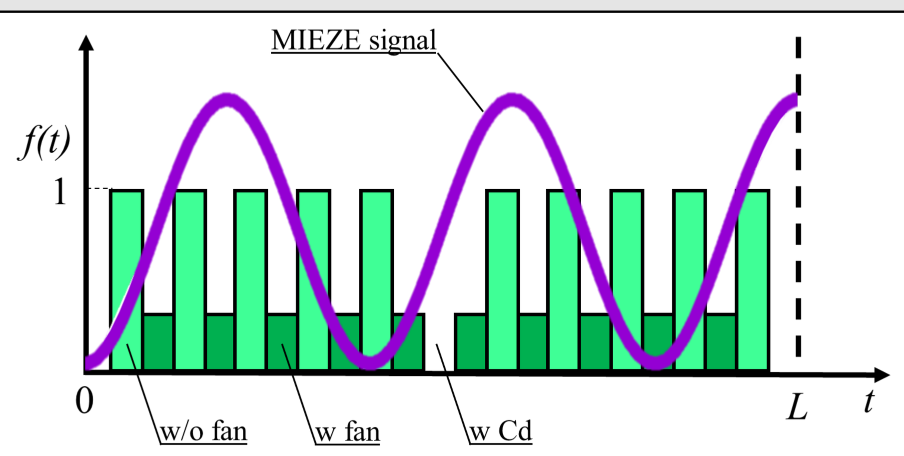

Fig.6 MIEZE signal and sample motion $f(t)$ (with period L) as functions of time.

1. The measured signal is given by the time integral of the product of the MIEZE signal and the sample motion[Fig.6].
2. For a MIEZE frequency between 0.5Hz to 360Hz, neutron counts were measured for a fixed duration. Then another phase of RSF2 was selected and the same measurement was conducted.

Results and Discussion

Experimental Results

Measurement data at high rotation speed for three RSF2 phase ($\chi_1 = 0°$) [Fig.7,8,9].

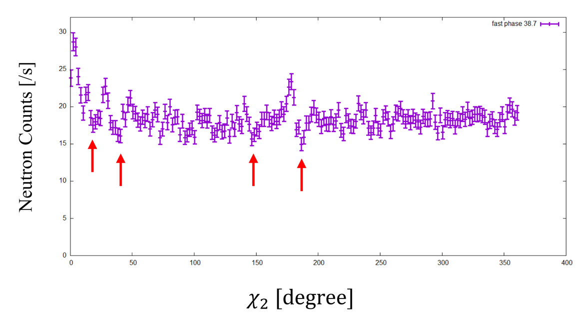

Fig.7 $\chi_2 = 38.7°$

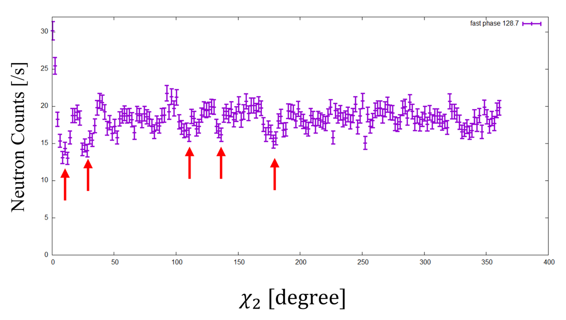

Fig.8 $\chi_2 = 128.7°$

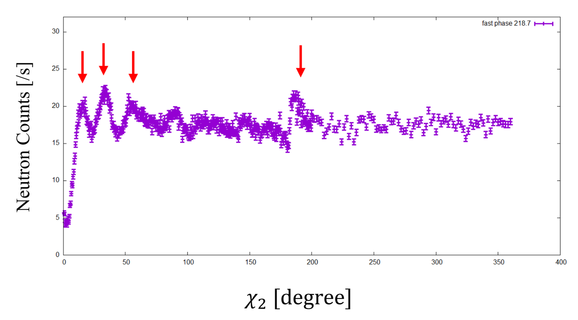

Fig.9 $\chi_2 = 218.7°$

As show in Fig. 7, 8 and 9, characteristic increases and decreases of the neutron counts were observed at integer multiples of the sample's frequency ($\simeq$ 17Hz). Notably, changes in neutron counts were observed near the 1st, 2nd, 3rd, and 11th harmonics of 17 Hz.

The MIEZE method was successfully applied to measure the frequency of a sample oscillating at low frequencies.

Discussion

$$I(\omega_m,\chi_2) = \frac{T}{L}\times\left(\int_0^{C_2}\frac{A}{2}(1-cos[\omega_m t+\chi_2+\phi])f(t)dt + \int_{C_2}^{C_1}\frac{A}{2}f(t)dt + \int_{C_1}^{L}Af(t)dt\right)$$

I: the measured intensity[/s], ω_m: MIEZE frequency[Hz], A: the amplitude of the neutron beam[/s],
C_1, C_2: time length of current applied to RSF1 and RSF2[s],
L: the period of the sample[s], T: the measurement time[s]

$$\int_0^{C_2} f(t)\cos[\omega_m t+\chi_2+\phi]\,dt \simeq 0.7501L - \frac{2L}{AT}I(\omega_m,\chi_2)$$

⇨ Neutron counts I should give Fourier component of the sample oscillation

Data analysis is in progress.

Conclusion

We successfully performed frequency measurements of a rotating fan using the MIEZE method. Preliminary results indicate that the method is capable of detecting periodic signals corresponding to the sample's motion.

Further analysis, including signal reconstruction and model validation, is still in progress to fully evaluate the method's accuracy and applicability.

Reference

[1] Badurek, G., H. Rauch, and J. Summhammer. "Polarized neutron interferometry: A survey." Physica B+ C 151.1-2 (1988): 82-92.
[2] Köppe, M., et al. "Prospects of resonance spin echo." Physica B: Condensed Matter 266.1-2 (1999): 75-86.
[3] Norio, A, et al. (2003). "*Chuseishi Supin Kogaku* [Neutron Spin Optics]." Kyushu University Press.