Improvement for Neutron Brillouin Scattering Experiments on High Resolution Chopper Spectrometer HRC

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Abstract. Neutron Brillouin scattering (NBS) experiments can be performed on the High Resolution Chopper Spectrometer (HRC). Recently, an intensity gain of a factor 2.4 with an improved resolution for NBS has been obtained by improving the detector system, the Fermi chopper, and the collimator system. This improved performance provides opportunities for intense studies of dynamics in condensed matter by using non-single-crystal samples.

1. Introduction

Neutron Brillouin scattering (NBS), that is inelastic neutron scattering near to the forward direction, is effective for observing coherent excitations in non-single-crystal samples such as ferromagnetic spin waves in powder samples and acoustic phonons in liquids and polycrystalline samples. In order to detect such excitations, access to the energy-momentum space near to the (000) wave-vector is required. In fact, the scattering intensity from ferromagnetic spin waves remains near to (000) only and is rapidly decayed with increasing $Q$ by the powder average. The energy-momentum space near to (000) can be accessed by using low-angle detectors, high-energy neutrons and high resolution.

The High Resolution Chopper Spectrometer (HRC) is being operated at the Materials and Life Science Experimental Facility (MLF), Japan Proton Accelerator Research Complex (J-PARC) to study dynamics in condensed matter with high resolutions using relatively high energy neutrons [1-5]. The HRC is a chopper spectrometer: a pulsed neutron beam is monochromatized by a Fermi chopper [6] and the neutrons scattered by the experimental sample are detected with a large area detector system. From the scattering angle ($\phi$) and the time-of-flight of the detected neutron, the neutron counts are converted to the dynamical structure factor as a function of the momentum transfer $Q$ and the energy transfer $E$. On the HRC, a range of incident neutron energies $E_i = 5 - 2000$ meV is available and an energy resolution of $\Delta E/E_i = 2\%$ can be achieved by using $E_i \leq 300$ meV for NBS, where the energy resolution $\Delta E$ is defined as the energy width (full width at half maximum) of the elastic scattering.

The HRC has a detector array of $^3$He position sensitive detectors of 2.8 m long and 3/4 inch diameter located at 4 m from the sample position covering $\phi = 3 - 62^\circ$ for conventional experiments, and another detector array of $^3$He position sensitive detectors of 0.8 m long and 1/2 inch diameter...
located at 5.2 m at \( \phi = 0.6° - 2.8° \) for NBS [1]. The partial pressure of \(^3\)He gas is 1.8 MPa and 2 MPa for the detectors of lengths 2.8 m and 0.8 m, respectively. The collimator system has two collimators composed of vertical slits of sheets of Cd, and it is effective for background noise reduction at low angles [2,4]. Either of the two collimators with 1.5° or 0.3° collimations can be selected, reducing the background noise at low angles; these collimations can reach a minimum of \( \phi = 3° \) for conventional experiments and \( \phi = 0.6° \) for NBS experiments, respectively. The area of each collimator is 60 mm \( \times \) 60 mm, that is larger than the beam cross section, and its length is 150 mm. Therefore, a setup for NBS has been provided on the HRC since its initial installation, and thus, results from NBS experiments were obtained [3].

The experimental conditions required for NBS are realized with the HRC, since it has detectors at low angles down to \( \phi = 0.6° \). In Fig. 1, the scan locus for a detector at \( \phi = 0.6° \) with \( E_i = 100 \) meV and the upper limit of the accessible energy-momentum space for \( \phi = 5° \) are indicated. The area between these two lines is the energy-momentum space expanded by using the NBS option of the HRC, and, at J-PARC. NBS experiments can be performed only on the HRC [3,4].

In this paper, recent progress on improving the performance for NBS on the HRC is described.

2. Improvement for NBS on HRC

Since the solid angle of detecting area for NBS experiments is little and limited to very low scattering angles, improvement for gaining the scattering intensity is essential. We made some efforts to gain the neutron flux in some ways.

The configuration of the detectors for NBS was improved. In the low angle detector bank, detectors are aligned in a double layered configuration to increase the counting rate: the detectors in the front layer face the sample and the detectors in the rear layer are placed just at the lower stream of the front layer. Neutrons transmitted through the front layer are detected with the rear layer. The counting rate for the double layer configuration is increased by a factor 1.4 to that for the single layer configuration for \( E_i = 100 \) meV, as shown in Fig. 2(a). The detectors are now mounted in the range of \( \phi = 0.6° – 5.1° \).

The Fermi chopper is composed of a slit package, which is a layered assembly of components of shielding plates and spacers sandwiched by curved walls. The slit package of a vertical slit, with cross section of 75 mm (width) \( \times \) 64 mm (height) and length of 100 mm, is inserted into a cylindrical rotor with diameter 125 mm and it rotates around the vertical axis [6]. The rotor and the slit package are distorted by the rotation stress at the frequency up to \( f = 600 \) Hz, and its performance becomes worse than the designed one. In the Fermi chopper in the initial setup (Fermi-B), the slit package, where the sum of the widths of the components equals to 75 mm, was inserted. In this assembly, a large distortion of the slit package occurs by the rotation stress. In the present arrangement, the slit package

![Figure 1. Energy-momentum space of NBS on HRC. The dashed curve is the scan locus for a detector at \( \phi = 0.6° \) with \( E_i = 100 \) meV, and the chain line is the upper limit of the accessible energy-momentum space for \( \phi \geq 5° \). The dispersion relation of spin waves in La\(_{0.8}\)Sr\(_{0.2}\)MnO\(_3\) observed at 245 K with the HRC is indicated with a fitted curve \( E(Q) = DQ^2 \) with a constant \( D \) (solid line) [3]. The short vertical bars represent the statistical errors. The vertical dashed line at \( Q = 0.225 \) Å\(^{-1}\) is the scan for the data in Fig. 2(c).](image-url)
Figure 2. Improvement for NBS experiments on HRC. (a) Detector configuration. Observed scattering intensities from the vanadium sample, which are integrated over the positions $p$ along each detector at $E_i = 100$ meV, are plotted as a function of the detector number $d$, where $d = 2$ and 26 correspond to $\phi = 0.6$ and 2.8° for the front layer, respectively. Due to an incomplete mask for the sample, a direct beam spreads from low angles. The intensities at higher angles (larger $d$) are free from the spread and show the actual intensity gain. The inset shows the double-layered configuration in the side and top views, the colored areas indicate detectors. (b) Slit package of Fermi chopper: Fermi-A (improved) and Fermi-B (initial setup). Inelastic spectra from the vanadium sample observed at 5.2 m from the sample using the 0.3° collimator (short) are plotted with fitted curves with Gaussian functions. The inset shows inelastic spectra from the vanadium sample using the 1.5° collimator observed at 4 m from the sample. (c) Total intensity gain. Spin waves in $La_{0.8}Sr_{0.2}MnO_3$ were observed with $E_i = 100$ meV by using the double-layered detector system, the Fermi-A, and the long collimator, also by using the single-layered detector system, the Fermi-B, and the short collimator. The solid lines are curves fitted to the scattering function for resolution-limited spin waves.

The collimator system was also improved. The transmission of the 0.3° collimator is 0.2, that is only 40% of the designed one. The transmission can be estimated by $T = \frac{w}{(w+t)\left[1+\frac{\Delta\theta}{(w/L)}\right]^{1/2}}$, where $t = 0.1$ mm, $w$, $L = 150$ mm, and $\Delta\theta$ are the thickness of the Cd sheet, the spacing of the slit, the length of the collimator, and the beam divergence of a neutron beam incident on to the collimator. The collimation is defined by $w/L$. For $E_i = 100$ meV, $\Delta\theta = 8$ mrad. The transmission can be estimated to be $T = 0.48$ for the 0.3° collimator with $w = 0.8$. This is because it is hard to maintain the flat plates of the thin Cd sheet with $t = 0.1$ mm. If the distortion of the Cd sheet is constant, $T$ should be increased for longer $L$ with the collimation $w/L$ unchanged. A long collimator was introduced, where $w = 1.55$ mm, $L = 295$ mm, i.e., $w/L = 0.3\circ$, and the cross section was slightly reduced to 59 mm $\times$ 54 mm. Hereafter, the previous 0.3° collimator is called the short collimator. At present, we can select one of the four: the long collimator, the short one, the 1.5° one, and the blank.
In order to evaluate the performance of the presently-improved system, an NBS experiment for a polycrystalline sample was performed. The sample was a nearly-cubic perovskite ferromagnet La$_{0.8}$Sr$_{0.2}$MnO$_3$ with the ferromagnetic transition temperature $T_C = 319$ K [3], with weight 23 g, and the beam cross section was defined to be 32 mm $\times$ 34 mm by Cd plates. The measurement was performed at 245 K ($< T_C$) with $E_i = 100$ meV at $f = 600$ Hz, by using the double-layered detector system, the Fermi-A arrangement, and the long collimator. Figure 2(c) shows an observed spectrum, where the background measured with an empty can was subtracted. The spectrum is well fitted to the scattering function for resolution-limited spin waves [3]. Also, the observed spectrum in the same condition but by using the single-layered detector system, the Fermi-B arrangement, and the short collimator [3] is plotted in Fig. 2(c). This spectrum is also fitted to the scattering function for resolution-limited spin waves. From the intensity factors obtained by the fits, a factor 2.4 was obtained as the intensity gain. Since the gain for the double-layered detector system to the single one is 1.4 and the gain for the Fermi-A to the Fermi-B is 1.1, the gain for the long collimator to the short one can be estimated to be 1.6.

3. Summary
From NBS experiments on the HRC, results have been obtained from studies on spin waves and phononic excitations mainly under the initially realized conditions [3-5]. By using the improved conditions, further results are expected. The NBS option differentiates the HRC from other chopper spectrometers, and opens opportunities for contributing to current science by measuring coherent excitations from non-single-crystal samples.

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