Nuclear Instruments and Methods in Physics Research A 721 (2013) 17–20

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

A new 40 m small angle neutron scattering instrument at HANARO, Korea

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ARTICLE INFO

Article history:
Received 15 July 2012
Received in revised form
19 January 2013
Accepted 15 April 2013
Available online 26 April 2013

Keywords:
Small angle neutron scattering instrument
Neutron flux
Q-range
Neutron velocity selector
Detector

ABSTRACT

A new 40 m Small Angle Neutron Scattering (SANS) instrument was constructed, and has been opened to outside users since November 2010 at HANARO, Korea. The instrument is equipped with state-of-the-art components, and the performance of the instrument is comparable to that of advanced SANS instruments. The flux at the sample position is measured as $2.9 \times 10^7/\text{cm}^2\,\text{s}$ with a wavelength of 5 Å and a collimation length of 1.7 m. The Q-range of the instrument covers from 0.0007 to 1.1 Å^{-1} when the lens option is applied. In this paper, the design and characteristics of the 40 m SANS instrument are described, and data showing their performance are presented.

1. Introduction

The Small Angle Neutron Scattering (SANS) technique non-destructively probes structures in materials at the nano-meter length scale (1–1000 nm), and has been a very powerful tool in a variety of scientific/engineering research areas: polymers, biopolymers, complex fluids, colloidal systems, protein folding and protein complexes, the flux-line lattice in superconductors, and nano-magnetic materials including magnetic recording media, metals and alloys, and ceramics. There are one or more SANS instruments installed in neutron scattering facilities [1–6]. The HANARO cold neutron research facility project was launched on July 1, 2003. The state-of-the-art SANS instrument was selected as a top-priority instrument by an instrument selection committee, which consisted of domestic users and HANARO personnel. To optimize the instrument layout and enhance the instrument performance, a Monte Carlo simulation was performed, and the 40 m SANS instrument was designed based on the simulation results [7,8]. The small angle neutron scattering instrument was constructed in November 2010 at the cold neutron source of the 30 MW HANARO research reactor in the Korea Atomic Energy Research Institute (KAERI), and has since been in user operation.

In this study, the characteristics of the 40 m SANS instrument are described, and the performance test results are presented.

2. Main hardware features

The 40 m SANS instrument at HANARO features a conventional 40 m length pinhole instrument. Fig. 1 shows a photo of the instrument. The instrument is located at the end of the CG2A guide, which was designed and constructed for optimizing the performance of the SANS instrument based on the simulation results. In the design and construction phase, we divided the instrument into four parts, a bunker, a collimator, a sample stage, and a detector vessel.

The bunker is made of 200 mm thick lead and 50 mm thick borated polyethylene. The lead is used as shielding materials to maximize the shielding efficiency since the space for the bunker is very limited. Inside the bunker, a main shutter, a neutron velocity selector, a neutron monitor, and an inserting guide are installed sequentially from the exit of the CG2A guide. The main shutter is made of lead and boron containing rubber, and is moving vertically with pneumatics. For safety reasons, we adjusted the shutter such that it moves automatically into a down position upon gravity and blocks the neutron beam in the absence of electricity or compressed air. The polychromatic beam from the guide is monochromatized by a helical slot velocity selector. The

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http://dx.doi.org/10.1016/j.nima.2013.04.052

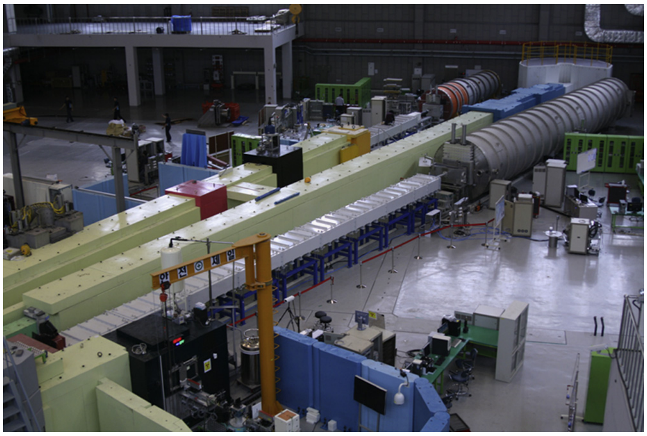

Fig. 1. Photo of the 40 m SANS instrument at HANARO.

velocity selector was supplied by Astrium [9]. The velocity selector is installed on a Huber goniometer, which allows the selector to tilt on a range of −5° to +5° with respect to the primary beam direction. Tilting the selector with respect to the beam direction changes the effective pitch of the helical pathways as well as the wavelength spread, $\Delta\lambda/\lambda$, where $\Delta\lambda$ is the FWHM (full width at half-maximum) of the wavelength distribution, and λ is the mean wavelength of outgoing monochromatized neutrons. Installed next to the velocity selector is a low-efficiency He-3 neutron counter, which monitors the intensity of the monochromatized neutron beam. To reduce the loss of neutrons in the empty space after the bunker, a guide with a length of 600 mm is inserted between the bunker and the collimator.

The monochromatic beam is collimated by circular apertures in the 20 m long pre-sample flight path of the instrument. The collimation system of the instrument comprises a quick shutter, an attenuator setup, 10 sections of collimator boxes, and a beam tube after the final collimator box. The pneumatically moving quick shutter is installed just before the first collimator box. The quick shutter opens and closes automatically as the measurement starts and ends with respect to the instrument control program. The attenuator is made of plexiglass with different thicknesses. The collimator boxes consist of eight 2 m length collimator boxes and two 1 m length collimator boxes. Each collimator box has a horizontally translatable table and their positions are controlled by a stepping motor and encoder system. Each collimator box has four positions: guides, a source aperture, an empty position and options. There are neutron guide elements with a $50 \times 50\ mm^2$ cross section and a source aperture on the table inside the collimator box. An additional source aperture or an optical option is going to be placed in the position reserved for options in use. By inserting guide elements into the beam path in the box, the effective source-to sample distance can be changed from 1.7 m to 20 m to vary the beam divergence and flux on the sample. The last guide inserted is immediately followed by a source-defining aperture with a 50 mm in diameter made of sintered B_4C. When the source to sample distance is 20 m (no guides are inserted), the source aperture size can be chosen to be either 12 mm or 24 mm depending on whether the lens option is applied. As a special feature, a laser to adjust the sample position of the neutron beam is installed in the second to last collimator box.

As options, a transmission polarizer and MgF_2 focusing lenses are installed in the collimator system [10,11]. The transmission polarizer with a length of 1.8 m and $m = 2.6$ which was supplied by SwissNeutronics, is located in the first collimator box. In addition to the polarizer, an RF type spin flipper is installed in the last collimator box. The polarized neutrons for the SANS experiments are available in the instrument using these devices. It was shown that multiple refractive biconcave focusing lenses are a very cost-effective way to improve the Q resolution of the SANS experiments, where Q is a momentum transfer. Compared with a regular pin-hole SANS, the intensity gain of the focusing lenses are greater than one order of magnitude at a minimum Q of 0.001 Å^{-1}. In the last collimator box, 28 biconcave MgF2 lenses with a diameter of 25 mm are installed.

There is a sample chamber that can be under vacuum or inert gases as a standard setup in the sample stage. There is also a rotation and translation sample table on which various sample environments can be placed. Both the sample chamber and sample table are located on the linear motion rail parallel to the beam direction, and thus both setups can be positioned at the same location where the minimum sample-to-detector distance is satisfied with an easy mechanism. Currently, there is a two-story changer with 30 samples for room temperature, a changer connected to a circulation bath with 10 samples for temperature controlling from −20 °C to 80 °C, a heating block for 5 samples with a temperature of up to 300 °C, and an electromagnet with a magnetic field of up to 1.8 T as sample environments.

A two-dimensional neutron position-sensitive detector, which was supplied by ORDELA Inc. (model no. 21000N), is placed in the detector vessel. The 21000N model has an active area of 98 cm × 98 cm and a $5.1 \times 5.1\ mm^2$ pixel area and utilizes a multi-cathode and preamplifier-per-cathode design (192 × 192 wires) with a mixture of 3He and CF4 gases at an absolute pressure of 125 kPa. The detector vessels were constructed using non-magnetic stainless steel and evacuated to a pressure below 1 mtorr, with an inner diameter of 2.5 m and a length of 20 m. The center position of the vessel is offset by 25 cm from the neutron beam center to increase the effective coverage area of the detector. A detector carriage mounted on a rail system enables the detector to travel along the length of the vacuum vessels providing sample-to-detector distances of 1.15–19.8 m. The carriage is also equipped with 4 beam stops with varying sizes. The detector has the ability to translate 50 cm off-axis on the carriage to expand the dynamic Q-range.

The instrument control system includes three Windows computers, a detector PC, a NVS (Neutron Velocity Selector) PC, and a main control PC. In the detector PC, high voltage is controlled, and data acquisition and a real-time display are realized by DAS 100 software supplied by ORDELA Inc. The rpm of the NVS is controlled, and the status of the operation conditions of the NVS is monitored in the NVS PC. The main control of the instrument is performed using a Lab-View based instrument control program (ICP) in the main control PC. In the main control PC, all motors and sample environments are controlled directly, while the detector PC and NVS PC are remotely controlled. The data reduction is performed using an IGOR-PRO-based software package, which was originally developed by NIST and is currently modified for HANARO SANS data [12].

3. Performance

The wavelength of the instrument was calibrated measuring a silver behenate standard sample. The wavelength can be identified by measuring the standard sample, of which we know the lattice spacing with two different sample-to-detector distances. We measured the silver behenate sample at sample-to-detector distances of 2.5 m and 4.2 m with varying NVS rpms. Fig. 2 shows the wavelengths with NVS rpms and good linear relations between the wavelength and the inverse rpm.

The flux at the sample position was measured both by a gold foil activation method and by using a He-3 neutron monitor for various collimation lengths and neutron wavelengths. The flux values measured by the neutron monitor are rescaled using the