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New neutron imaging facility at the NIST

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Abstract

The design objective of the thermal neutron radiography facility at the National Institute of Standards and Technology (NIST) Center for Neutron Research was to provide a large beam diameter and a high fluence rate in order to produce images of dynamic systems. A thermal neutron beam with a 14 cm diameter thimble was chosen. The beam was initially filtered by a 10 cm thick single crystal bismuth filter cooled with liquid nitrogen. The beam exiting the port is shaped using either a 1 cm or 2 cm diameter pinhole to form a uniform high fluence rate beam at the sample. The resulting neutron beam at the sample has an L/D ratio of 280 with a fluence rate of $1.84 \times 10^7\,\mathrm{cm^{-2}\,s^{-1}}$ and 560 with a fluence rate of $4.75 \times 10^6\,\mathrm{cm^{-2}\,s^{-1}}$ uniformly spread over a 26 cm diameter beam. To capture the neutron beam image a scintillator and CCD camera is used. The current neutron camera system is limited to a 2.5 s frame rate; however, a high frame rate detector system based on amorphous silicon will allow frame rates to meet the design goal. Samples can be rotated and translated in situ for radiography and tomography applications. This facility became operational in early 2003. Since then the facility has been translated backwards by ≈ 2.13 m and 5 cm of bismuth was added to the filter. The design of this facility and the impact of the later changes are discussed.

Keywords: Neutron; Radiography; Imaging

1. Introduction

The new neutron radiography facility, located at Beam Tube 6 (BT-6) at the National Institute for Standards and Technology (NIST) Center for Neutron Research (NCNR), has recently been commissioned and is currently operating. The design goals of this facility are to perform

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dynamical studies of proton exchange membrane fuel cells (PEMFC). The region of interest in PEMFC is the membrane region, with a typical length scale $\approx 50\,\mu$m. The active area of a single standard testing PEMFC is $\approx 50\,\text{mm} \times 50\,\text{mm}$. Neutron imaging facilities should be sensitive to water laminar thicknesses of 10–50 μm, at spatial resolutions less than or at 200 μm, and at image acquisition times less than 1 s. This requires an extremely high thermal neutron fluence rate and large length to aperture diameter ratios (L/D).

2. Flight path design

BT-6 views the reactor core through a 14 cm thimble, with a heavy concrete plug lined with a conically tapered collimator shown in Fig. 1. The tapered collimator is formed by 1.5 mm thick borated aluminum to collimate the thermal neutrons and 10 cm thick steel inserts to stop the fast neutrons and gamma-rays. The inserts have a through hole that gradually reduces in diameter from 14 cm to 3.4 cm at the exit. After the collimation, the high-energy neutrons and gamma-rays are attenuated by a single crystal bismuth filter cooled by liquid nitrogen, discussed in more detail later. Downstream the beam can either be stopped or shaped by a rotating, 60 cm thick, heavy concrete drum with four positions. There are currently two used positions for shaping the beam with either a 1 cm or 2 cm aperture with extra steel/boron aluminum yielding an angular divergence for the 1 (2) cm aperture of 0.85° (1.02°). A third open position is currently unused, and the fourth position acts as a beam stop. The drum is supported and rotated about the axis of the cylinder.

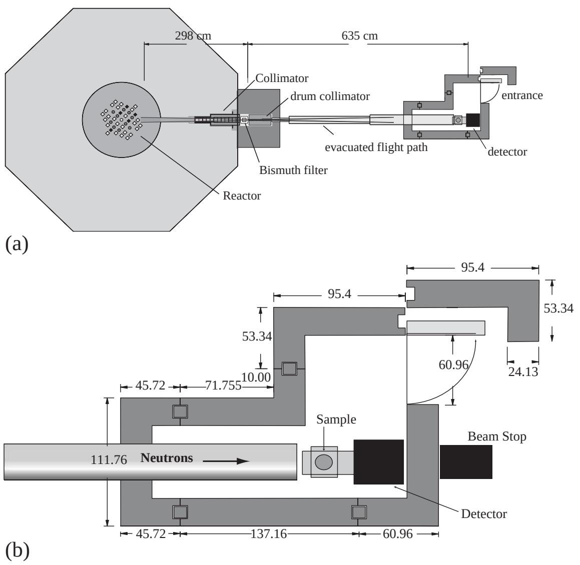

Fig. 1. (a) The overall top view of the facility in relation to the reactor. (b) The sample hut in which the detector and experiment are located. All dimensions are in centimeters.

The flight path from the exit of the drum collimator to the sample location is evacuated to avoid air scattering. The previous BT-6 configuration had a flight path of 4.2 m from aperture to detector giving a L/D of 170–350 (estimated from measurements described later). The facility was moved farther downstream ≈ 2.13 m in order to accommodate space requirements of other neutron scattering instruments. This places the current detector location at 6.35 m from the drum collimator. We have measured the current L/D for the 2 cm aperture with the American Society for Testing and Materials (ASTM) standard E 803 using the linear regression technique yielding $L/D = 281 \pm 7$, see Fig. 2. Due to space limitations at the sample location the L/D gauge could not be moved sufficiently far from the detector. Assuming that L/D scales linearly with aperture size, we estimate that the 1 cm aperture has $L/D \approx 570$. Note that the previous L/D ratio at the 4.2 m position was never measured and was estimated using the same scaling method. The uniform region of the beam for the 2 cm aperture is ≈ 25 cm in diameter, and a scan of the beam using a Fuji image plate [1] is shown in Fig. 3.

In the previous configuration the neutron beam was filtered by 10 cm of single crystal Bi which led to rather high radiation levels near the facility. Spatial constraints in the 6.35 m location prohibited the addition of shielding; therefore, an additional 5 cm of cooled single crystal bismuth was added. Based on Monte Carlo calculations of the incoming neutron spectrum from the reactor core [2] and the available total cross sections for single crystal Bi [3], the additional Bi reduces the fast (thermal) neutron fluence rate by a factor of ≈ 2 (1.3). Using a