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The new Cold Neutron Radiography Facility (CNRF) at the Mianyang research reactor of the China Academy of Engineering Physics

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Abstract

A new cold neutron radiography beamline has been designed and constructed for the Mianyang reactor at the Institute of Nuclear Physics and Chemistry of the China Academy of Engineering Physics. This paper describes the components of the system and demonstrates the achievable image resolution.

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Keywords: Cold neutrons; Neutron radiography; Neutron imaging; Neutron tomography

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1. Introduction

A new cold neutron imaging facility (CNRF) has been designed, manufactured and successfully commissioned at the Institute of Nuclear Physics and Chemistry (INPC) of the China Academy of Engineering Physics (CAEP). This was a collaborative project between INPC, SCITEK and RadSci..

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The CNRF utilises a neutron beam extracted from the liquid hydrogen cold source that is located at the position of peak thermal neutron flux in the heavy water reflector around the core of the SPRR-300 research reactor. This beam-line extends into a new guide hall (Fig. 1).

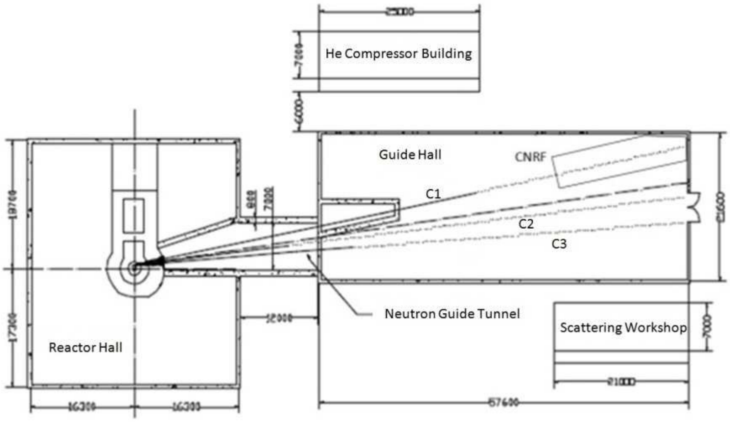


Fig. 1. Schematic drawing of reactor guide hall layout

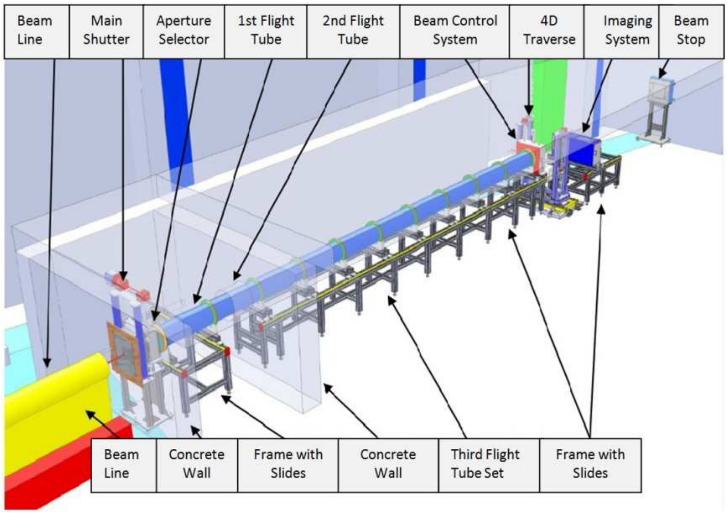


Fig. 2. CAD 3d drawing of CNRF.

The guide hall currently features three neutron guides – C1, C2 and C3 - with the most probable neutron wavelengths for each of these neutron beams being 0.2nm, 0.4nm and 0.6nm respectively.

2. Description of system

The CNRF (Fig. 2) is located on guide C1 which has a total length of 62m (curved section length 23.5m). Two gaps are provided in this guide for future installation of graphite and silicon monochromators that would be used to produce beams for neutron spectroscopy.

The main flight tube is made up of ten 1m long segments of Al pipe with high-vacuum flanges and seals that can be easily modified to provide access for an imaging system at an intermediate (higher neutron beam intensity) position along the flight tube (Fig. 3).

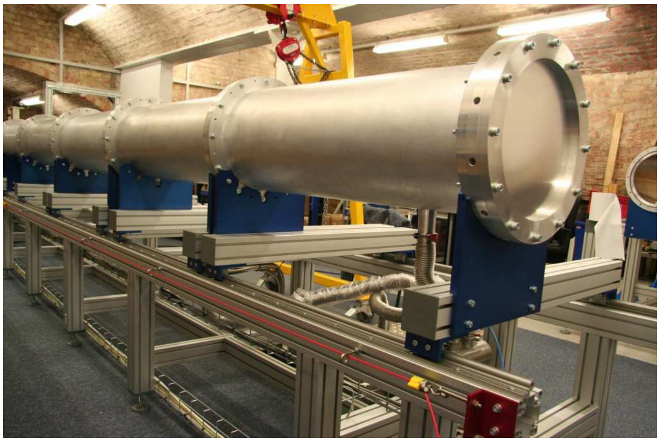


Fig. 3. A section of the flight tube on its support frame

Fig. 4. Main shutter and automated aperture selector

Beam divergence is controlled using aperture rings of boron carbide boxed in aluminium located inside the flight tube. Their position may be altered to suit the location of the imaging system.

The neutron guide terminates at a 200mm x 30mm exit aperture in the front wall of the beamline area and in front of which is located the main shutter for the beam mounted on a steel plate attached to the wall. The main shutter incorporates 5mm thick boron carbide plates and 150mm thick lead in the movable section (Fig. 4). Operation is fail-safe, with control being carried out using electro-magnets. A fast shut-down within 0.5 seconds is achieved.

The aperture selector consists of a set of boron carbide plates, each having a different diameter central hole, mounted on a linear traverse that is fitted with a stepper motor. Aperture diameters range from 1mm to 30mm, providing L/D values of between ~11,000 and 370 for an 11m flight path.

Test objects are mounted on a four-axis traversing system fixed to the beam hall floor (Fig. 5(a)). The X,Y and Z axes can carry test pieces of up to 300Kg in weight and have a positional accuracy of 10 microns. The fourth axis is a rotating stage for tomography applications and is designed for the inspection of objects no more than 20kg in weight.

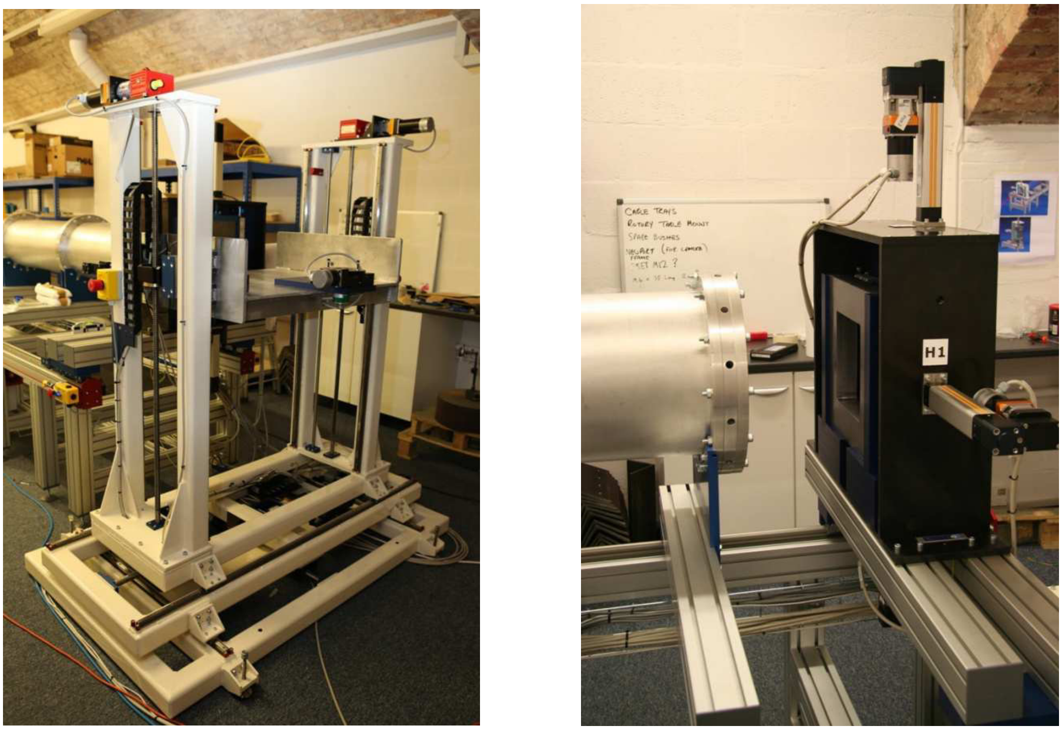


Fig. 5. (a) Four-axis object handling system; (b) beam area control plates

The open beam area at the end of the flight tube is defined using two pairs of boron carbide plates backed with lead, with each plate controlled by a stepper motor. This enables the beam to be configured to the size of the test object (Fig. 5(b)).

The imaging system uses an Andor iKon-L DW936 camera mounted in a light-tight aluminium enclosure (Fig. 6) with a mirror at 45° to view a 50 micron thick enriched Li6-ZnS scintillation screen. The camera is set up on a motorised traverse in order that lens focusing can be carried out remotely.

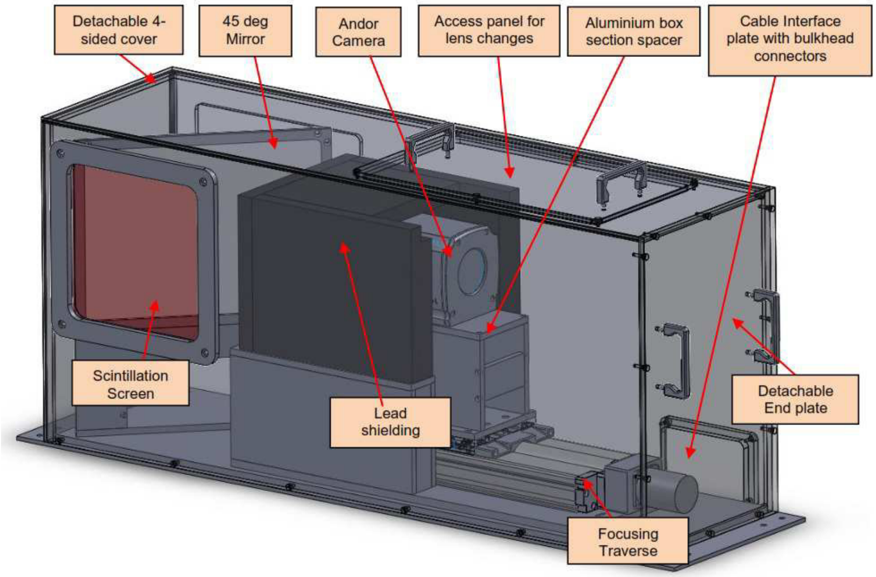
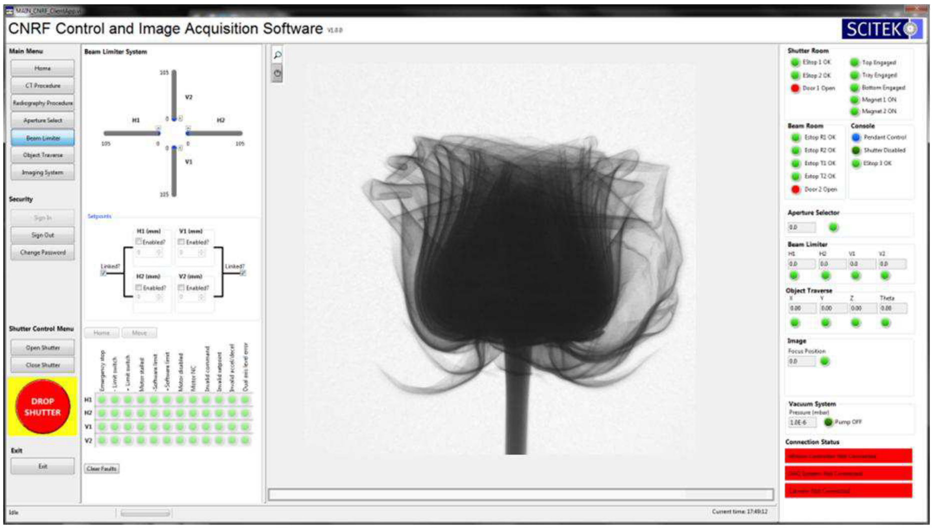


Fig. 6. Design of the neutron imaging housing

4. Control and analysis Software

The control of all the equipment is carried out by a National Instruments cRio system that communicates over Ethernet with the control PC(s) that feature a graphical user interface. A Trio motion control system is used to control 11 traverse stages. The Control and image capture software was written in LabView and a typical screen is shown in Fig. 7 below.



Aperture Selector: 0.0
Beam Limiter: H1 0.0, H2 0.0, V1 0.0, V2 0.0
Object Traverse: X 0.00, Y 0.00, Z 0.00, Theta 0.00
Image – Focus Position: 0.0
Vacuum System – Pressure (mbar): 1.0E-6
Current time: 17:49:12

Fig. 7. Combined System Control and Image Capture software – Typical Screen

The complete system incorporates 3 PCs in a Windows 7 environment operating on a fiber optic gigabit network. Two PCs could be used to control the system and allowed image capture and automated CT scan.

Octopus software is used for tomographic reconstruction of neutron images whilst VGStudio Max provides 3D image display and analysis capabilities.

5. Neutron imaging system performance

The performance of the complete imaging system was evaluated using different image quality indicators, including the Siemens star developed by Grünzweig et al. (2007) at PSI. For each of the three lenses, selected to provide the required pixel size and field of view, images of this Gadolinium test object were obtained for resolution and contrast studies. Analysis of the images obtained (Fig. 8) gave the contrast ratio results for the 2 lp/mm resolution sector shown in Table 1. The contrast ratio was determined by plotting the pixel intensity over a number of line pairs (shown at the 3 o'clock position) near the 2 lp/mm outer edge of the Siemens star and determining the average ratio of maximum to minimum values. The image quality obtained for each lens surpassed the desired requirements.

Table 1. Contrast ratio from the Siemens star for different fields of view.

Lens Focal Length [mm]	Field of View [mm]	Required Contrast Ratio at 2 lp/mm [%]	Achieved Contrast Ratio at 2 lp/mm [%]
50	195x195	6	6.3
85	90x90	13	16.4
135	48x48	15	15.4

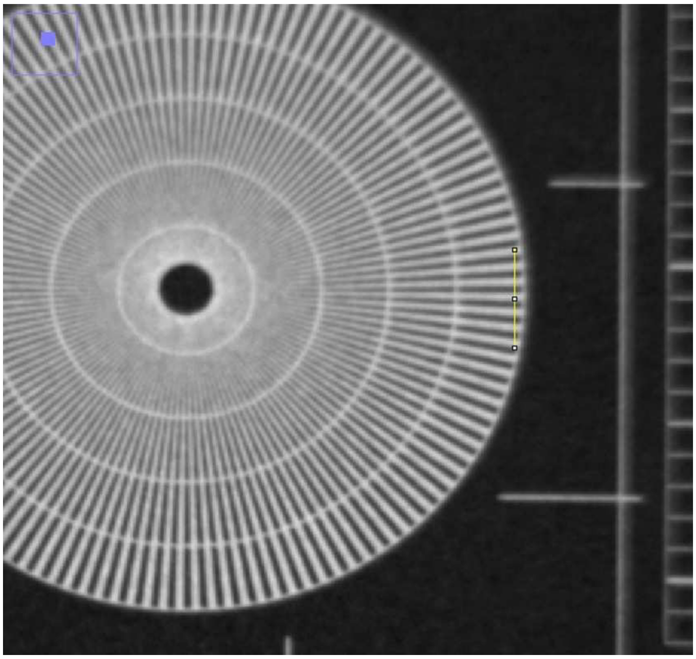


Fig. 8. Neutron image of the PSI Siemens star

Fig. 9. CT scan of an optical encoder

In addition, a CT scan was carried out of an optical encoder used on the four-axis object handling system. Octopus software reconstructed the 3D data and VGStudio Max generated the 3D graphical displays of the tomographic reconstruction. These results demonstrate the high quality image data that is achievable with this cold neutron radiography facility.

6. Conclusions

All the equipment for the Cold Neutron Radiography Facility has been demonstrated to meet design specifications and the system is now in routine operation and being used to investigate a range of scientific applications.

7. Acknowledgements

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