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THE NEUTRON RADIOGRAPHY/CT STATION AT CPHS

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ABSTRACT

A neutron radiography/CT station will be built during the first-phase construction of the Compact Pulsed Hadron Source (CPHS) at Tsinghua University, China. We report in this paper the physical design of this instrument, including the overall layout and anticipated performance, the configuration and functionality of major components, and the direction of future development.

1.Introduction

The Compact Pulse Hadron Source (CPHS) project, launched in 2009 at Tsinghua University in Beijing, China, aims at the establishment of a modern compact neutron/proton source for education, research, and accelerator-based technological development. Located on the main campus of Tsinghua University in Beijing, the CPHS produces protons by a linear accelerator and long-pulse neutron beams by injecting the protons on a neutron target-moderator based on the Be(p,n) reaction. A neutron radiography station and a small-angle neutron scattering instrument are among the first set of scattering instruments to be constructed. A more detailed description of the CPHS project is given in an accompanying paper by J. Wei et al. in this proceedings.

The CPHS neutron radiography station is currently under design study. The result indicates that, even at a moderate neutron-flux level, this station, if effectively coupled with the available resources of the university, may serve the purposes of student training, instrumentation development and industrial application, and eases the heavy demand for neutron imaging and radiography in China.

2. System Layout

The beam-line of CPHS neutron radiography station uses a simple pinhole geometry. Neutrons emerging from the moderator surface travel through a 3m-long steel collimator, with the beam cross-sectional area converging over three segments of the collimator from a diameter of 8cm to 4 cm, see Fig. 1. An opening along the way is reserved for the possible installation of a filter or chopper device to select a desirable neutron wavelength bandwidth.

Directly downstream of the collimator is an area where the final aperture can be selected. Additionally, there will be space allowed for inserting the G0 grating for the phase-contract option of imaging, see components (6) and (7) of Fig. 1.

Downstream of the aperture are the sample table and experimental substations. The sample table is equipped with entrance and exit slits as well as rotational and translational manipulators so as to enable the neutron-beam exposure of a specific volume element within the sample at a desirable orientation. Rotational and translational scans are mainly for tomographic measurements. The substations include the modules for imaging, computerized tomography (CT), and neutron-induced prompt gamma-ray spectroscopy. Two positions for imaging, corresponding to the short and the long flight paths, are provided for small and large samples, respectively. The modules are joined by evacuated flight tubes for the definition of the neutron flight paths from the aperture to sample and for background reduction. The G1 and G2 gratings may also be inserted behind the sample for the phase-contrast imaging option. Another module for neutron-induced gamma-ray analysis can be incorporated concurrently with imaging.

Therefore, the overall design of the beamline permits conventional imaging with a choice of two fields of view, CT, phase-contrast imaging, and prompt-gamma analysis. We anticipate that the compactness of the source and the modest neutron flux (at least initially) will provide us the flexibility needed for testing the various devices and evaluating the performance of different modules as well as providing basic service of conventional neutron imaging to users at the early stage.

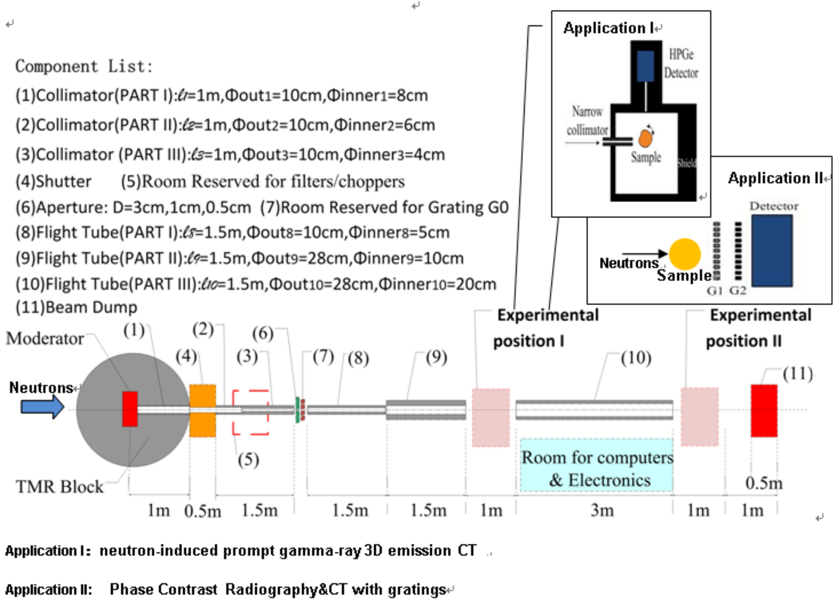

Fig.1. A top view of the general layout of the CPHS Neutron Radiography Station (without shielding structures), including approximate dimensions of key components

Technical Parameter	Value
Target/moderator	Beryllium/ solid methane(≤20K)
Source Frequency	50Hz
Field of View	FOVmax =20×20 cm2
Flight path(moderator-> pinhole)	3m
Flight path (pinhole->sample)	Lmax = 6m

Spatial resolution	~0.1mm×0.1mm
Divergence	L/D=100~400
Detection systems (intended)	• Scintillator+ high-resolution CCD camera • Image Plate
Additional Modules	• CT • Phase Contrast Imaging (gratings) • PGA-ECT

Table.I. Design performance of the whole radiography station (source intensity, wavelength, L/D, etc)

3. Structural Specification of Key Components

3.1Collimator

The CPHS radiography station uses square steel pipes as the outer support structure of the collimator. For the ease of installation and length adjustment, the collimator is divided into three evacuated sections, each in the length of about 1 m, either connected together or segmented with separated windows. Fig. 2 shows the side view of the entire collimator. We plan to use epoxy-lead composite to fill in the inside of each pipe and to overlaid the inner surfaces with B-Al-alloy sheets. One-cm thick B4C baffles are to be inserted at proper locations, see Fig. 2, so as to eliminate, as much as possible, the neutrons reaching the aperture through internal reflections by the surfaces. This defines the inner diameter for the appropriate convergence. The steel pipes, except for the in-pile segment, are covered with an epoxy-lead and an epoxy-borate-poly composite layer, each about 20 cm thick, to shield against neutrons leaking out from the beam tube or entering from the environment.

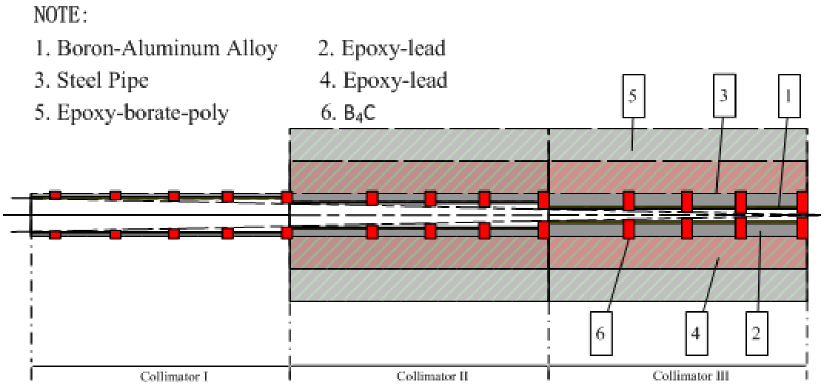

Fig.2.Side View of the Designed Collimator Structure in CPHS Neutron Radiography Station (including materials of each layer)

3.2 Aperture

The size of the aperture, 4.0 (fully opened), 3.0, 1.5 and 0.5 cm in diameter (referd as D in this thesis) and a fully closed configuration, is selectable from a rotatable wheel as shown in Figs. 3. The neutron-absorbing material of the apertures is made with Li2CO3-

and LiF-loaded epoxy slabs for keeping a minimal gamma-ray emission from the neutron capture processes. The fully open beam is intended for use in conjunction with the coded-aperture imaging technique. The fully closed position is used to block the beam.

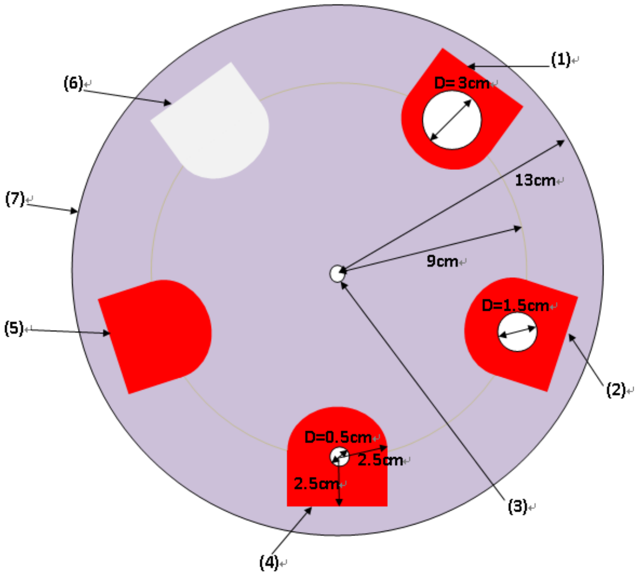

Fig.3.Skematic of the whole aperture wheel in CPHS Neutron Radiography Station (key dimensions included)

3.3Flight Tube

The structure of the flight tube is similar to that of the collimator. Modules of 1.5 m and 3 m long, each separately evacuated, will be used so that an aperture-to-sample distance (referred as L in this thesis) can be varied from 1.5 to 6 m. The tapered opening of the flight tube permits an enlarging viewing area with increasing flight distance, from 5cm ×5cm at 1.5 m to 20cm×20cm at 6 m.

3.4 Detector: Scintillator+ CCD camera

The first goal of the neutron radiography station is to perform conventional neutron transmission imaging. This is achieved by placing a scintillator screen behind the sample to convert the transmitted neutron into light. The light is then reflected by a mirror away from the direct neutron beam, entering a converging lens to form images using a CCD camera. The schematic setup is shown in Fig. 4. The intended components to be acquired commercially are listed in Table 2.

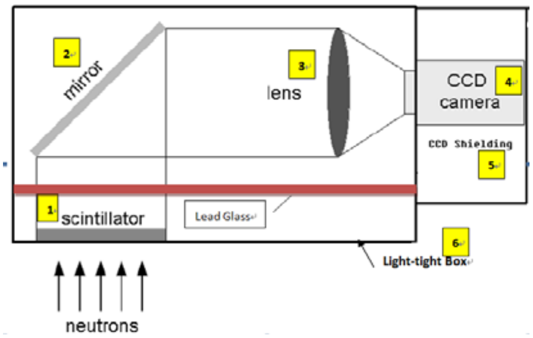

Fig.4. Schematic Layout of the Scintillator+CCD camera System in the CPHS Neutron Radiography Station

	Item	Manufacturer	Model
1	Scintillator Screen	Applied Scintillation Technologies	SecureX ND 20cm×20cm
2	Mirror	Edmund Optics	4-6 wave Mirror 254mm×313mm NT32-248
3	Lens	Nikon	AF Nikkor 85mm f/1.4D IF
4	CCD camera	Andor	iKon-L DW936N-BV pixel size=13.5μm 2048×2048
5	CCD shielding	In-house fabrication	
6	Light-tight box	In-house fabrication (about 104cm×45cm×35cm)	

Table. II. Component Selections of the Scintillator+CCD Camera System in the CPHS Neutron Radiography Station

4. Further Development of Imaging Technology

4.1 Design philosophy

Neutron and x-ray techniques are similar in many aspects, but realizing the different nature of these probes and taking advantage of their complementarity will generate new potentials in scientific applications through advancement of the individual or combined methodology. With regard to imaging and radiography, Tsinghua University has extant capability and experience in x-ray applications, CPHS is interested in the development of the neutron counterpart for eventually an x/n synergetic technology. The design philosophy of our neutron radiography station pays heed to the flexibility of a small source, the flexible module structure of the experimental platform, and the intended cross-fertilization with other programs in the university. Obviously, our neutron experience is thin, so we aim at a modest start, i.e., conventional imaging, but leave plenty of room for modification and expansion. At the same time, we are aware of the rapid development of this field and wish to collaborate with sister laboratories in the world community.

4.2 Neutron tomography

The first extension beyond conventional imaging is CT. The schematic sketch of such idea is shown in Fig. 5. We plan to adapt the sample manipulation hardware and software currently available from the x-ray programs at the Department of Engineering Physics, Tsinghua University. On the neutron side, which we have no prior experience, we shall experiment with different detector prototypes and data-analysis schemes. We are aware of the progress in neutron tomography at foreign facilities, such as SINQ at Paul Scherrer Institute[1], the FRM of TU München [2] , et al, and wish to establish collaboration with the experts in this field.

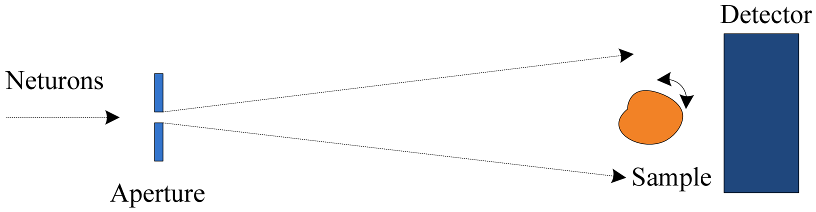

Fig.5. Top view of the sketch map of conventional radiography & CT in the CPHS Neutron Radiography Station

4.3 Phase Contrast Imaging

Exploration of the phase shift of neutron waves caused by neutron-matter interactions in the sample is another area of interest. Again, neutron phase-contrast imaging and CT lags behind the development of the electromagnetic-radiation-based techniques. Several neutron phase contrast imaging methods, such as interferometer-based [3], analyzer-based [4], propagation-based [5] and grating-based [6] schemes, have been developed to retrieve phase shift information, some of them take advantage of the unique magnetic interaction of neutrons with matters [7]. We shall first focus on the grating-based imaging method because of its relaxed requirement for spatial coherency of the neutron beam. A conceptual sketch of the grating-based phase contrast radiography & CT at the CPHS station is shown in Fig. 6. The key component is a set of 3 gratings. The source grating (G0) is an array of neutron-absorbing lines, fabricated using Gd-containing or other high neutron-absorbing materials, located next to the aperture for the generation of an array of 1-D neutron line sub-sources. Another absorption grating (G2) together with a low neutron-absorbing grating (G1) are place behind the sample. A phase-stepping approach by moving G1 or G2 relatively step by step over one grating period is adopted to measure phase shifts [6]. Currently we are investigating the suitable gratings for this method and hope soon to begin fabrication process of the gratings.

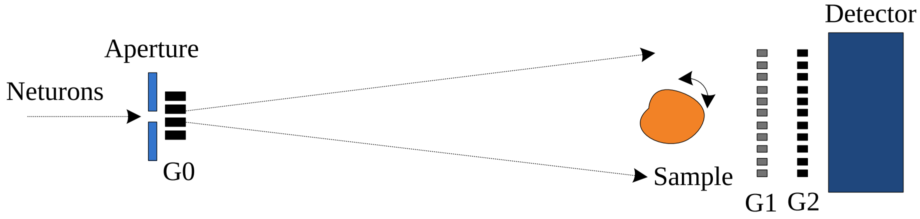

Fig.6. Top view of the skematic map of phase contrast radiography & CT in the CPHS Neutron Radiography Station

4.4 Prompt Gamma-ray Analysis & 3D emission CT

Neutron-induced prompt gamma-ray activation analysis (PGAA) which uses the element-specific prompt gamma-ray emitted by the excited compound nucleus for chemical analysis of the sample is a well-known technique. First, we plan to establish a conventional PGAA module at a 90° scattering angle so that we may perform PGAA concurrently with conventional imaging. Next, we are interested in the neutron-induced prompt gamma-ray 3D emission CT (PGA-ECT) method which applies the CT technique for the reconstruction of the spatial images of the isotope(s) that caused gamma-ray emissions in the object. PGA-ECT instruments using fast or thermal neutrons have been successfully implemented in several neutron sources [8-10]. We recognize the availability of cold-to-epithermal neutrons at CPHS and hope to explore the feasibility of PGA-ECT method on our station. To this end we shall use a band-width selecting neutron chopper to control the matching of the neutron energies with the resonance energy of the activation. A conceptual sketch of the PGA-ECT module is shown in Fig. 7. A high-energy resolution HPGe detector is used to analyze the emitted gamma-ray spectrum, either from a volume pixel within the sample defined by narrow entrance and exit slits, or from selected regions chosen under a CT operation mode.

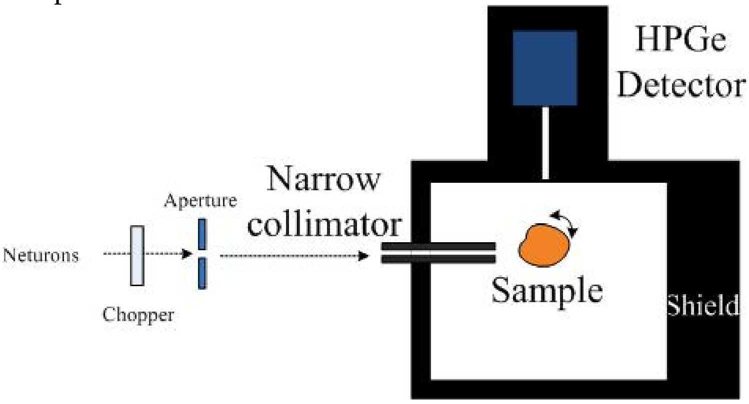

Fig.7. Top view of the sketch map of PGA-ECT in the CPHS Neutron Radiography Station

4.5 Energy-dependent Imaging using Time-of-flight Techniques

The time structure of a pulsed neutron source presents an inherent niche for investigation of energy-dependent features in time-of-flight imaging. Much progress has been advanced by pulsed sources researchers in recent years, notably the works by Kiyanagi et al. of Hokkaido University [11,12]. These researchers combine time-of-flight transmission cross-section analysis with high-resolution 2-D imaging to obtained information regarding the microstructure and texture in engineering materials. We shall investigate the applicability of this technique on instruments of long-pulse sources such as the CPHS.

5. Conclusion

We have described the physical design of a neutron radiography/CT station to be built at the CPHS of Tsinghua University. While conventional neutron imaging is the first goal of this instrument, we have adapted a design philosophy by which further development of additional capabilities, from CT to phase-contrast imaging to PGA-ECT modes, can be implemented as modules of the beamline and their performance be tested conveniently. Many rapidly developing fields in China such as functional materials, space aviation, energy systems, archeology and cultural heritage, and other disciplines can be benefited by neutron radiographic studies. We are confident that the neutron radiography/CT station of CPHS, through fulfillment of its design goal and optimization of its operation, will serve and profit many users.

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