Neutron Imaging System Improvements

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Service Provided: Neutron Beam Laboratory

Sponsors: U. S. Department of Energy Innovations in Nuclear Infrastructure and Education (INIE) grant, Pennsylvania State University Radiation Science and Engineering Center, Pennsylvania State University Department of Mechanical and Nuclear Engineering, a private automotive manufacturer

Introduction

The growing demand for dynamic neutron imaging (radioscopy), especially for fuel cell research, has stretched our existing neutron imaging capabilities. These included developing a more efficient means of data acquisition and storage, better post processing techniques, and a more accurate quantification of water present in the radioscopic images. To this end, the neutron imaging team at the Radiation Science and Engineering Center (RSEC) has made several fundamental and very advantageous changes to its equipment and software resources. The following sections describe the recent upgrades to our imaging and post-collection image processing systems.

For many years our dynamic imaging system consisted of an analog camera connected to a computer through an analog-to-digital interface card that allowed the capture of 30 fps images at 640x480 and 8-bit grayscale depth. This system provided a stable foundation to support the development of data capturing and post processing procedures. Last year a "turn-key," completely digital, image acquisition system was added.

Neutron Computed Tomography

A Neutron Computed Tomography (NCT) system is being developed to compliment our neutron imaging capabilities. The neutron imaging facility has been upgraded with the addition of a 10 bit CCD camera and installation of a GdO_2S scintillator, and a new neutron computed tomography system has been installed, including hardware and software systems and a new computer system for data acquisition and reduction. The newly developed neutron tomography system consists of a neutron beam source, an object turntable, a scintillator screen, a cooled CCD camera, mirror, and computer system (Figure 1). The neutron beam is approximately 30 cm in diameter, and with a L/D ratio of 150 (ASTM 803) at the scintillation screen. The thermal neutron flux intensity at 1 MW power is $1.7*10^7$n/cm^2-s, with a maximum divergence half-angle of 1.4^o. A precise tomography object turntable is fixed to a sample position so it can rotate to different positions and orientations, and is remotely controlled by computer. The attenuated neutrons are detected with a GdO_2S scintillator which converts the neutron beam to light photons through neutron capture reactions. The photons are then detected by a photocathode that converts photons to electrons through photoelectric effects. The phosphorescent output screen then converts the intensifier electrons into visible light that pass through a lens and enter into the CCD camera. The active diameter of this Thomson tube is 23 cm (9 inch), and yields a light gain of approximately 10^3.

Image data are collected in a 10-bit format. Image acquisition and reconstruction is done by two different computer workstations. One computer provides the control to the CCD camera and object turntable as well as image data capture functions. The other provides tomography cross-section reconstruction and image visual analysis functions.

The most important requirement for a CCD neutron tomography detector is its light sensitivity. In the Penn State Radiation Science and Engineering Center, a Cohu 7700 CCD camera with a sensor array format of 1004$\times$ 1004 pixels is used, with a spatial resolution of (148*148) μm^2, and image integration times from 1/30 s up to 36 minutes. The CCD camera is light shielded by a tube, which prevents natural light from interfacing with the emitting light of the scintillator. The tube serves as a positioning device for the detector components. The tube has been designed according to the boundary conditions given by the size and shape of the individual detector components, as well as the desired image size and the space available at the facility.

The new system being designed will not use the Thomson intensifier but will instead use a cooled, low-light CCD camera. The light emitted from the scintillation screen is reflected by a mirror and viewed directly by the CCD camera, allowing the user to see the detailed geometrical information of a sample object. Special precautions have been made in the design of the CCD camera to remove the camera from the direct neutron beam to avoid radiation damage on the chip.

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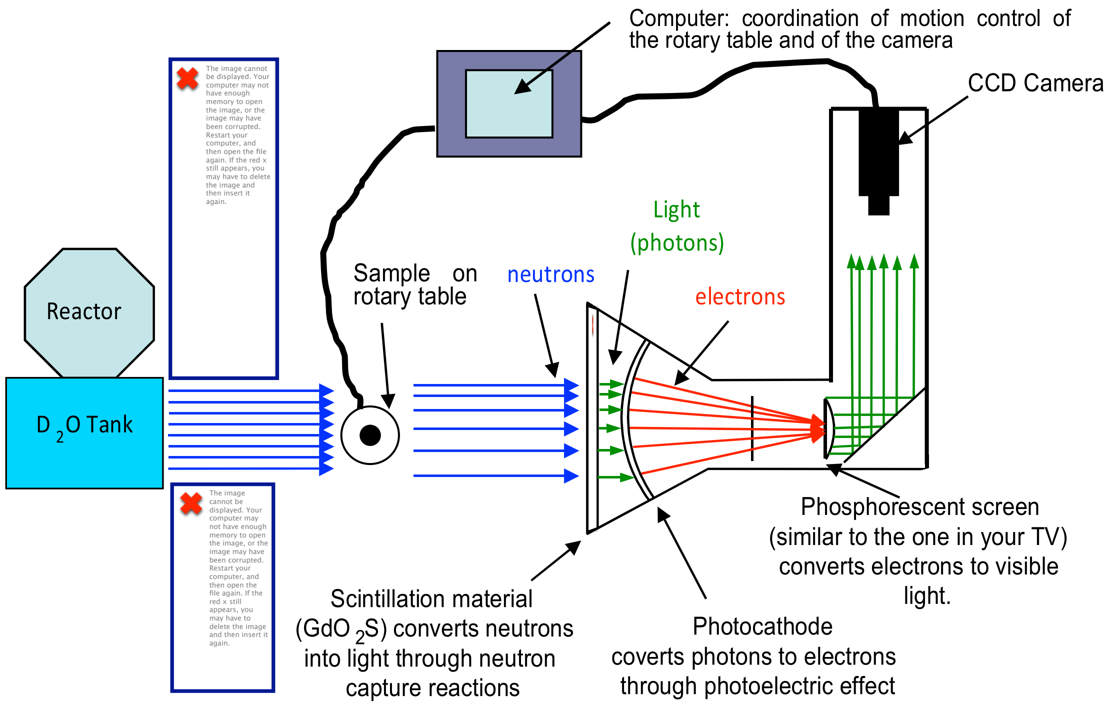

FIGURE 1: Sketch of a neutron tomography system

Experimental NCT Setup and Results

The imaging camera is controlled by the computer and can be easily synchronized with a computerized motion control system such as rotary table. Image data is digitized and can be immediately used for the 3D reconstruction. A computer synchronizes the rotary table and the electronic imaging device so that a sequence of digital images from different view angles is taken automatically and stored on the computer system. A Newport 855C rotary table controller with resolution of 0.001^{o} has been installed and a plug-in developed to control motion and image collection. This system is used to rotate sample objects.

A new data processing computer has been purchased, along with the neutron tomography reconstruction software Octopus 8.0. A 3-D visualization program, VG Studio Max 1.2 was also purchased.

A bubble level gauge on the rotary table is used to see if the rotary table axis is correctly aligned. We can also check the alignment by placing a sample test object on the rotary table, taking an image, and rotate it by 180^{0} and take another image. The second image is flipped and subtracted from the first image and if the resulting image is totally dark, then the rotary table is adjusted well. Otherwise, the rotary table needs to be adjusted.

The following are general steps to perform image reconstruction:

1) Acquire images from each projection,

2) Correct for reactor power fluctuation corrections

3) Correct for white noise: In all images are taken by the CCD camera there are white spots caused by gamma radiation hitting the CCD chip. This correction is done by Octopus,

4) Correct for beam shape,

5) Calculate the 3-D voxel array using Octopus to determine the cross section information of sample object, and

6) Use VG-studio to obtain a 3D visualization of object volume: after getting the object cross section slices information from “Octopus”, the slices are integrated into the CT visualization software “VG studio Max to see the detailed internal information of the sample object.

The first reconstructions have been successfully made. Figures 2 and 3 show the radioscopic 2D image experimental measurements of an actual aluminum cylinder with copper tubing wrapped around the outside and detailed calculated cross section information using Octopus, respectively.

After successfully calculating the detailed cross section information using Octopus, the cross-section slices were input into VG-Studio Max software to visualize the object internal information. Figure 4 shows the volume reconstruction results using VG-Studio Max.

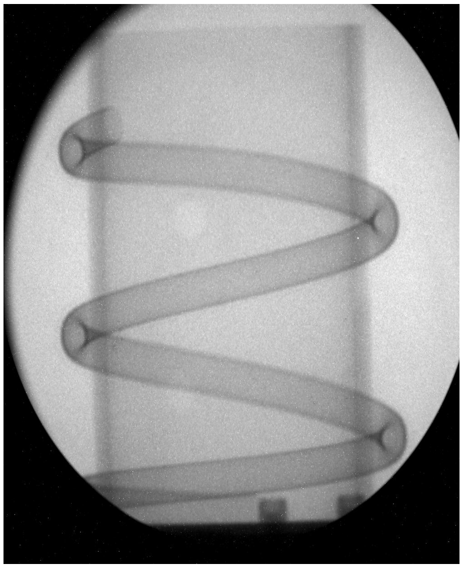

FIGURE 2: Two dimensional radioscopic image acquired with the upgraded imaging system

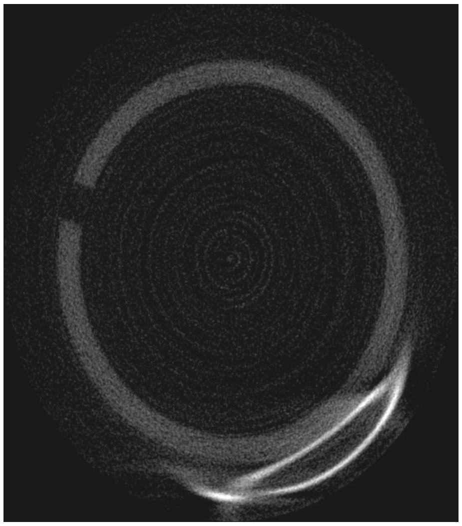

FIGURE 3: Sample aluminum cylinder with copper tubing wrapped around cross section information (361 projections in 180^{o} at 0.2 s /frame)

Clearly, the volume reconstruction of the aluminum cylinder with wrapped copper tubing is successful, although there are still some artifacts around the 3D images. These are due to the fact that we did not take enough radioscopic information (image slices), since this was only to verify the system and software.

Neutron Computed Tomography Water Quantification

Another important ongoing work is the technique for water quantification. To gain a better understanding of the fidelity of the NCT reconstruction software, we generated several ideal CT data sets. We used the simple neutron attenuation equation to model a simple object like an aluminum cylinder with copper core in the center of the object. The purpose of doing this modeling work is to create ideal data sets which have no artifacts to investigate the neutron scattering effects of tomography and also to verify water quantification techniques and expected error. Figure 5 shows modeling results of an aluminum cylinder with copper core "radioscopic" image with calculated data using simplified exponential attenuation equation and the corresponding cross section reconstruction results using Octopus software.

After finishing the reconstruction calculation using Octopus, the cross-sectional slice information was put into VG-Studio Max visualization software to get the detailed internal information. Figure 6 shows the visualization results of the modeled object.

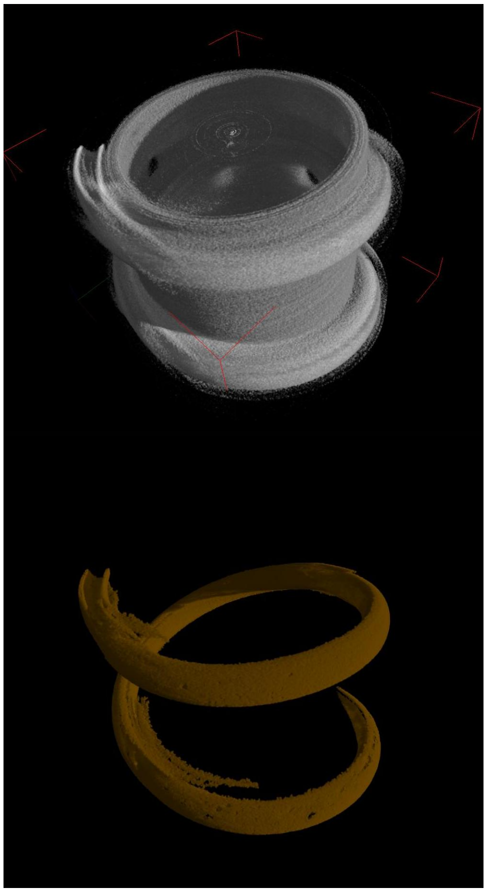

FIGURE 4: Volume reconstruction results of the aluminum cylinder with copper tubing wrapped around detailed internal information using VG-Studio Max.1.2

Future Work

Future improvements to the NCT system will focus on the following:

- Improving NCT system spatial resolution
- Increasing effective L/D ratio to reduce geometrical unsharpness
- Improving imaging system detector efficiency for low neutron flux
- Reducing artifacts in reconstructed slices
- Reducing radiation effects in projection images
- Developing the NCT water quantification method
- Using NCT to investigate water distribution in a fuel cell

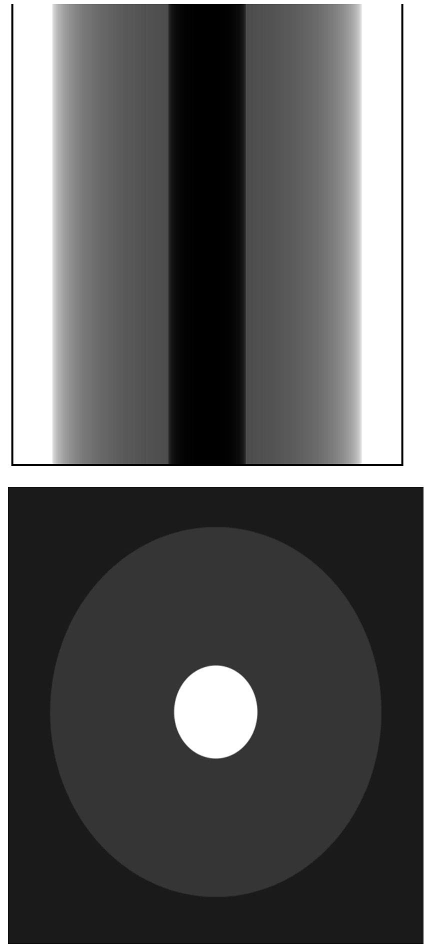

FIGURE 5: Aluminum cylinder with copper core "radioscopic" image with calculated data using simplified exponential attenuation equation and the corresponding cross section reconstruction result using Octopus software.

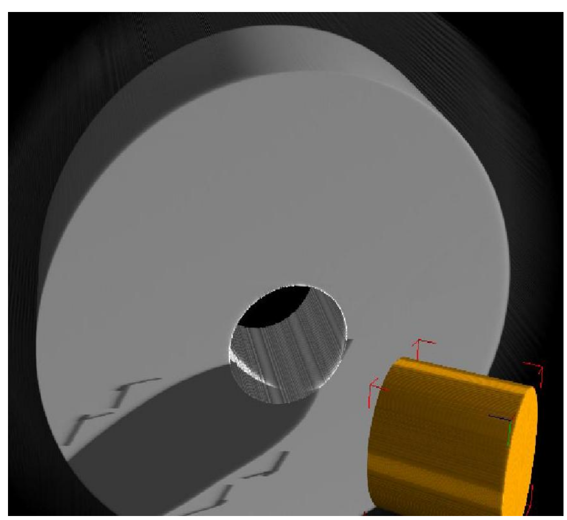

FIGURE 6: Visualization of the aluminum cylinder with copper core 3-D information using VG-Studio Max