Neutron imaging at Peking University

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Abstract: Neutron imaging techniques were investigated at Peking University based on a 4.5 MV Van de Graaff accelerator. The thermal neutron radiography, fast neutron radiography and fast neutron resonance radiography were tested. The low neutron flux limits the image quality. A new radio frequency quadrupole (RFQ) accelerator based on neutron source with a yield of 1 012 n/s is being set up.

Key words: neutron imaging; thermal neutron radiography; fast neutron radiography; fast neutron resonance radiography

1 Introduction

As a complementary technique of X-ray or gamma ray imaging, neutron imaging has been widely used around the world. However, neutron imaging usually based on a reactor or spallation neutron source, which are large and very expensive. An industry practical facility is usually compact, economic and has reasonable performance. Neutron imaging facility based on small accelerator, like radio frequency quadrupole (RFQ) accelerator, can meet these requirements. But it is suffering from low neutron flux, which means it is not easy to get high quality image on such a system.

In order to improve the quality of low flux neutron imaging, we set up a neutron imaging experimental platform on the Peking University 4.5 MV Van de Graaff accelerator, and carried out a serious of experiments.

2 Facility

This facility is based on the 4.5 MV Van de Graaff accelerator[1]. Two kinds of targets are used on this facility. One is thick solid beryllium target, which can produce neutrons with continuous energy under the deuteron beam bombardment. The neutron yields and angle distribution has been investigated[2-4]. A polythene moderator was used to thermalize the fast neutrons as shown in Fig. 1. This moderator was optimized to produce more thermal neutrons with limited fast neutron yield. The moderator can be removed during the fast neutron radiography experiments. Another kind of target is deuterium gas for fast neutron resonance radiography. In that case almost mono energy fast neutrons can be generated by D-D reaction at a special direction.

A cooled charge coupled device (CCD) camera with 1 024 × 1 024 pixels is used for imaging. Neutrons are converted into visible light by scintillation screen and recorded by the camera. An NDg scintillation screen from applied scintillation technologies was used for thermal neutron imaging. Several kinds of fast neutron scintillation screens have been developed at Peking University for fast neutron imaging[5, 6]. The CCD camera is sensitive for radiation. Gamma rays and neutrons can damage the CCD chip or cause some isolated snow spots in the output image. The CCD camera was surrounded by multi-layer shield to reduce the dose rate on the CCD chip[7]. Also a special image processing program was developed to remove the noise caused by radiation.

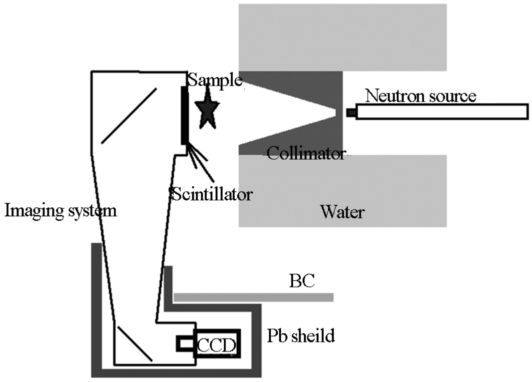

Fig. 1 Sketch map of the neutron moderator and imaging system

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3 Thermal neutron radiography

Thermal neutron radiographs were taken on this platform. The neutron yield is less than 10^{10} n/s. We selected a very low *L/D* ratio, 30, to increase the neutron flux to about 5×10^{3} n/($cm^{2}\cdot$ s), which is just sufficient for imaging [3]. The Cd ratio is 1.5. Fig. 2 shows thermal neutron radiographs of the image quality indicator and beam purity indicator, which were manufactured according to US standard ASTM E545 [8]. The image of the beam purity indicator shows there is little gamma component in the image. Limited by the low neutron flux and low *L/D* ratio, the space resolution is about 0.5 mm. Fig. 3 shows the pictures of thermal neutron radiograph and X-ray radiograph of a ball-point pen with metal cover. Its inner structure can be seen clearly in the neutron radiograph.

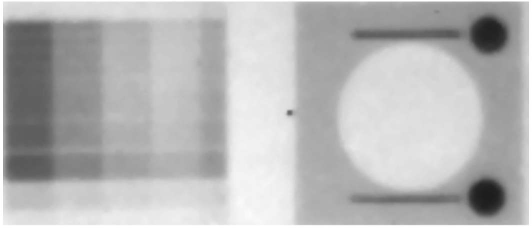
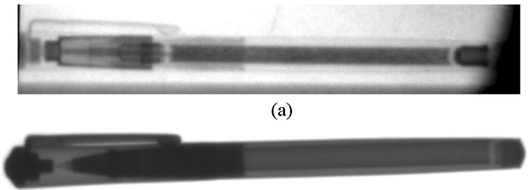

(a) (b)

Fig. 2 Thermal neutron radiographs of image quality indicator (a) and beam purity indicator of ASTM E545 (b)


(a)

(b)

Fig. 3 Thermal neutron radiograph (a) and X-ray radiograph (b) of a ball-point pen with metal cover

4 Fast neutron radiography

Large scale objects can be detected using fast neutrons, which have higher penetrability than thermal neutrons. However, the fast neutron scintillation screen is a bottleneck for fast neutron imaging. Common used fast neutron scintillators are low efficiency or sensitive to gamma. We developed a new scintillation screen with high neutron detection efficiency and low gamma responsibility, which is the wavelength-shifting fiber (WSF) converter [6]. It helps to improve the fast neutron image quality and neutron efficiency under very low neutron flux. Fig. 4 shows the comparing of images taken with new scintillator and conventional ZnS(Ag) scintillator. The samples were a lead step wedge and a polythene step wedge. The thicknesses of the lead step wedge are from 10 to 50 mm, while the thicknesses of the polythene step wedge are from 6 to 30 mm. The fast neutron flux is 2.3×10^{5} n/($s\cdot$ cm^{2}). The noise is much lower for the new scintillator. Fig. 5 is another image taken with this scintillation screen. The sample consists of two bottles of water inside a steel cylinder. The height of the water in the two bottles is different. The neutron radiograph showed that the liquid contained inside the steel shell is clearly visible.

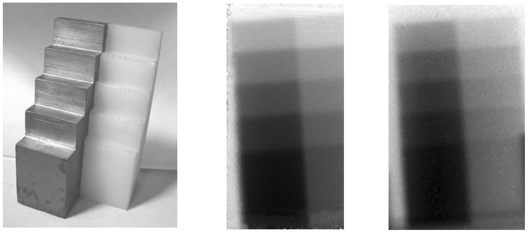
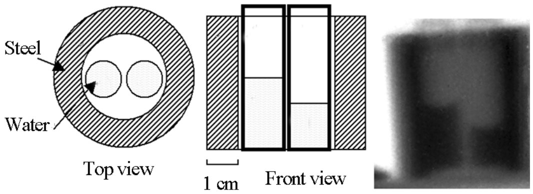

(a) (b) (c)

Fig. 4 Fast neutron radiographs of a stepped sample (a) taken with new fast neutron scintillation screen (b) and traditional ZnS(Ag) based fast neutron scintillator (c)



(a) (b) (c)

Fig. 5 Sketch map of a sample ((a) and (b)), and its fast neutron radiograph (c)

5 Fast neutron resonance radiography

We also carried out fast neutron resonance radiography experiments [9]. With this technique, the contrast of a particular element can be enhanced, or even the distribution image of a particular element can be taken. Fig. 6 shows an example. The sample consists of a group of graphite, aluminum and copper blocks with different thickness (Fig. 6(a)). We used 6.3 MeV (on the carbon resonance peak) and 6.1 MeV (out of the carbon resonance peak) neutrons produced by D-D reaction to get the carbon distribution image. As shown in Fig. 6(b), we cannot recognize the graphite from aluminum clearly with 6.1 MeV neutrons, but a carbon distribution imaging can be obtained through adequate treatment from the two radiographs taken with 6.3 MeV and 6.1 MeV neutrons as shown in Fig. 6(c), in which the images of aluminum and copper were removed.

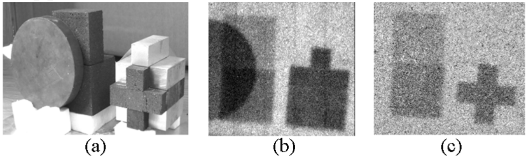


Fig. 6 The sample photo (a), its fast neutron radiograph with 6.1 MeV neutrons (b), and the carbon distribution image given by fast neutron resonance radiography (c)

6 Discussion and perspective

We are setting up a RFQ accelerator based neutron imaging system, PeKing University Neutron Imaging FaciliTY (PKU-NIFTY). This is a more practical neutron imaging facility comparing with the 4.5 MV Van de Graaff. Its fast neutron yield can reach more than 10^{12} n/s, and the thermal neutron flux at the imaging plan will be more than 10^5 n/ (cm^2 • s) when the *L/D* is 100, which can be used in some practical applications.

Our experiments on the 4.5 MV Van de Graaff accelerator show that it is possible to use low flux neutron source for neutron imaging with current imaging techniques. The neutron yield on this accelerator is no more than 10^{10} n/s, and the thermal neutron fluence at the imaging plane is only around 10^7 n/ cm^2 accumulated within an exposure time of one hour, which is only 1/10 of the fluence requirement to get a good quality image. The space resolution is limited by the low *L/D* ratio of this facility, too. However, the experiments also indicate that neutron imaging with good quality can be expected to be taken within tens of minutes with the new PKU-NIFTY. It is reasonable for some applications.

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