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Development of Fast-Neutron Imaging Techniques in Korea

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1. Introduction

Neutron radiography can provide a better contrast than X- and gamma-rays, because neutrons can pass with ease through lead and steel but are stopped by polymer, plastic, rubber, water, oils, etc. This means that neutrons are attenuated by hydrogen composite, but penetrate many heavy material such as tungsten and lead. From this point of view, neutron radiography is very useful technique for industrial applications such as inspection of aircraft corrosion, explosive devices for space technology, defects in casting and so on [1-8].

This work aims to investigate a possibility of fast-neutron imaging for industrial application in KSTAR

Since the successful first operation in 2008, the KSTAR tokamak D-D plasma operations have carried out for about three months every year. The D-D plasma operations during the campaigns have performed with ohmic heating and auxiliary heating such as neutral beam injection (NBI) and ion cyclotron range of frequency (ICRF). Neutrons produced in the 2014 KSTAR D-D plasma campaign have estimated to be about 10^{13} ~10^{14} neutrons /sec [9].

In order to carry out this work, we have adopted two fast-neutron imaging techniques as a digital imaging radiography based on a CCD camera, and a film-based imaging one. For comparison between both methods, a series of the fast-neutron imaging measurements have performed with various fast-neutron sources such as commercially available D-D neutron generator, and the D-D fusion neutrons generated from the KSTAR tokamak.

More details will be described in this paper.

2. Applied imaging methods

In this work, in order to make the fast-neutron image by means of a digital imaging technique, the fast-neutron imaging device based on a cooled-CCD camera has developed, The imaging device consists of a scintillator as neutron convert screen to generate visible lights, optical lens to collect the visible lights through the scintillators, a cooled-CCD camera to record patterns of collected visible lights, and PC to control the camera.

For the digital fast-neutron imaging radiography, Artemis LF40+ CCD camera and Nikon lens were chosen. These have the KAI-04022 Kodak sensor with 2048 x 2048 resolution pixels, and Nikon lens module (f:1.2), respectively.

On the other hand, an industrial X-ray film was also prepared for a film-based fast-neutron imaging by the way of analog method.

To make fast-neutron imaging, in general, the neutrons require a parallel beam and high-intense neutrons. Therefore, in this work, in order to make a parallel beam of neutrons in KSTAR, and shielding to avoid undesirable events from scattered neutrons and gamma rays, the collimator and shielding are calculated and designed by Monte Carlo simulation MCNP code. They are composed of high-density polyethylene (HDPE) and lead blocks. And then a series of measurements of fast-neutron imaging have carried out by using the developed digital fast-neutron imaging device and the film-based imaging technique.

3. Results

3.1 Fast-neutron imaging method in KSTAR Tokamak

The digital fast-neutron imaging based on a cooled-CCD camera was measured with the device installed on the midplane of outside of KSTAR tokamak. A cup filled with water, a mini spanner, and cylindrical-lead container to be tested as shown in Fig.1 was placed on the front of neutron convert screen of the device.

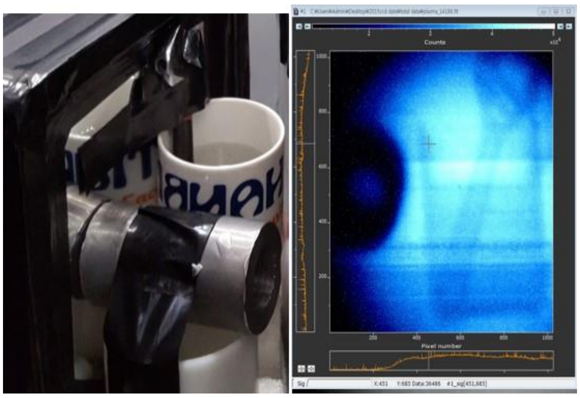

Fig.1 Photograph of a cup (left), and the fast-neutron imaging with the CCD camera in KSTAR tokamak (right).

The fast-neutron imaging with the CCD camera shown in Fig.1 was only taken by one plasma shot with time durations less than about 10 seconds. It is seen that KSTAR fast neutrons can be extended the applicability of the fast-neutron imaging for industrial applications

For the fast-neutron imaging by film method, a film instead of the digital imaging device was also set on the end of collimator of neutron beam.

Fig.2 Photograph of a cup filled with water, a mini spanner, and batteries (left), and the fast-neutron imaging by film method in KSTAR tokamak (right).

It was possible to obtain the fast neutron imaging with an industrial X-ray film in KSTAR tokamak. The fast-neutron imaging of cup filled with water, and other materials is shown in Fig. 2.

It is shown that the fast neutrons are attenuated by hydrogen composite.

3.2 Fast-neutron imaging method with the D-D neutron generator

Fig.3 Photograph of a machine drill (upper), and the fast-neutron imaging by film method with the D-D neutron generator (lower).

With commercially available D-D neutron generator having neutron yield of 10^7 neutrons/sec, it was obtained the fast-neutron imaging with an industrial X-ray film. The imaging of machine drill is shown in Fig.3. It is also shown that the fast neutrons are passed with ease through a part of steels but are stopped by a kind of plastic resin.

4. Conclusions

In this work, the fast-neutron imaging techniques have studied using the two different kind of D-D neutron sources with the same energy of 2.45 MeV.

The present results show that the fast-neutron imaging technique can be extended the applicability of the fast-neutron imaging for industrial applications.

It is conclude that static images of the fast-neutron digital imaging can become acceptable quality for image analysis, even though the digital imaging method on the basis of CCD camera offers highest speed but gives poorest image sharpness comparing to film-based imaging radiography. Since quality of the fast-neutron imaging based on a digital imaging technique is mainly affected by the factors such as gamma-ray content, type of converter screen, the improvement of digital fast-neutron imaging would be in achievable level enough if the factors were removed or reduced.

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