The Neutron Digital Radiography Facility Based CCD in SPRR-300

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Abstract. SPRR-300 is a Swimming Pool Research Reactor in China. The neutron digital radiography facility has been set up in it. The facility is made up of collimator system, the table for sample, the imaging system, the controlling system and so on. In the collimator system, the graphite is used as a moderator, and the bismuth as a gamma filter and the material made of lead, boron, polyethylene and cadmium as the diaphragm. The table for sample is used to modify the tested part and orientation of the sample. The converter is NNU-2(^{6}LiFZnS(Ag)) made in China. The CCD is used in the imaging system. To improve Signal-to-Noise of CCD imaging system, the double thermocouple refrigeration is used to cool CCD below -30℃. To improve resolution power, the high quality lens with small field of view is used to cover 10cm×10cm or 3cm×3cm. To improve dynamic range, the image grabbing, processing and analyzing technology of 14bit (16383) gray-data is used. A 10mm thick glass coated with Al and TiO_2 as the protecting layer is used to protect CCD directly irradiated by neutron. A light shielded box which material is Al to avoid long term activation is used. To improve dynamic range, the image grabbing, processing and analyzing technology of 14bit data is used. In the controlling system, PLC (Programmable Logic Control) is used to improve the facility automation and the radiation shielding of researchers and instruments. The neutron digital radiography has been utilized in SPRR-300 to detect internal structures or defects of some components, and some good effects were obtained.

Introduction

Neutron radiography is a non-destructive testing method that a object is penetrated by neutron and the information of its inner structure is obtained. It is the complementarity of X-ray and the other rays radiography, and it is a only available non destructive method in some situations[1, 2].
SPRR-300 is a Swimming Pool Research Reactor(3.5MW). It is a light-water moderated and cooled, graphite and beryllium reflected thermal reactor. The maximal thermal neutron flux in the core of SPRR-300 is about 6.5×10^{13} $n.cm^{-2}.s^{-1}$[3]. Neutron radiography has been developed in the reactor since 1980s, but with a stagnation of a long period. Now, neutron radiography has been re-developed during these years, and the Thermal Neutron Digital Radiography Facility (TNDRF) has been designed and set up in SPRR-300.

1. Structure of TNDRF

The structure of TNDRF is showed in Fig.1[3]. The neutron for neutron radiography is drawn from a radial thermal neutron channel, which diameter is 150mm. The 55mm lead plate in front of the channel is used to filter γ-rays from the reactor core. Graphite plug is placed in front of the channel to moderate neutron. The value of cadmium ratio (Rcd) obtained for gold foil on the orifice of the channel may adjusted from 4 to 150 if the length of graphite plug is changed from 0cm to 100cm. An interior collimator like a taper after the graphite plug is used to prevent the divergence of neutron flux.

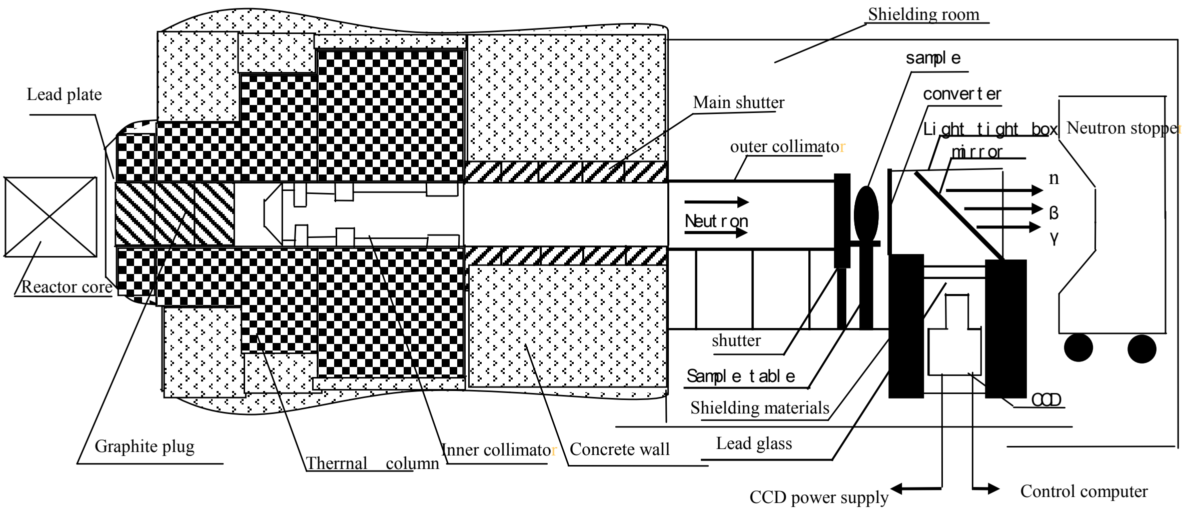

Fig. 1 The structure of TNDRF in SPRR-300

The interior structure of the interior collimator is like a labyrinth. On the one hand, the structure can reduce the weight of the collimator, and on the other hand, it can more effectively absorb scattered neutrons and γ-rays. The diameter of the diaphragm of the interior collimator can be changed between 10mm, 30mm and 50mm. Another bismuth plate of 45mm thickness in front of the inter collimator is used to stop γ-rays again. To increase collimation ratio, an exterior collimator like a taper is used, and collimation ratio can vary between 50 and 660 with the change of the diameter of the diaphragm and the length of the exterior collimator. The diaphragm of the interior collimator is composed of borated plastics, metal gadolinium or cadmium rings, and the inner surface of the interior and exterior collimator is lined by lead foil and boron carbonide to decrease scattered neutron and γ-rays. A shutter made up of water, lead and steel box is used to control the exposure time and enhance the shielding. The sample table is driven by three motors, and it can move left and right, up and down and round and round to adjust the angle and region of a sample, and it can be driven forward and backward by hand to adjust collimation ratio. The main imaging methods is the cooled scientific grade CCD (C-CCD). To improve Signal-to-Noise in C-CCD imaging system, the double thermocouple refrigeration is used to cool CCD below -25□. To improve resolution power, the high quality of the lens with small visual angle is used to cover 10cm×10cm (f: 188.7mm, f/D: 1.45) or 3cm×3cm (f: 225.7mm, f/D: 1.6). To improve dynamic range, the image grabbing, processing and analyzing technology of 14bit (16383) gray-data is used. The pixel array format of the C-CCD chip is 1024×1024 pixels with a pixel size of 24×24μm. The quantum efficiency of the C-CCD is in the range of 60%~80% for wavelengths from 350 to 800nm. A 10mm thick glass coated with Al and TiO2 as the protecting layer is used, and it has the high reflectivity (more than 90%) for the light emitted by the scintillator, generation of few γ-rays and no-lasting activation of the material. A light shielded box which material is Al to avoid long term activation is used. The converters used in SPRR-300 reactor are Gd foil, Gd_2O_2S foil for direct imaging, and Dy foil for indirect imaging, and NNU-2(^{6}LiFZnS(Ag)) for CCD imaging. Of course, the other two imaging methods are also used in SPRR-300 neutron radiography in SPRR-300, a method using films (including direct imaging and indirect imaging) and a method using intensified

CCD (I-CCD). Compared with C-CCD, the film method has better spatial resolution(about 30μm ~50μm), but requires more time for developing films, and the information of a photograph is more difficultly converted to digital data. The I-CCD system is often called the Real-time radiography, and its maximal frame speed is about 25frames/s, and the spatial resolution is about 200μm. The C-CCD system with about 100μm spatial resolution is also called the high resolution static system, and it takes about 0.5s~1800s to get a neutron radiograph according to the sample material and the neutron flux.

3. Parameters of TNDRF

a) The maximal flux on sample: $4\times10^{7}\cdot cm^{2}\cdot s^{-1}$.
b) Cd-ratio : 4□150 (Adjustable).
c) Collimator ratio: 60□660 (Adjustable)□
d) neutron-gamma ratio: $2.70\times10^{10} n.cm^{-2}.Sv^{-1}$.
e) ASTM-E545 indicator parameters (Cd-ratio is 15): NC-62.14%, S-0.95%, γ-0.71%, P-1.79%, H-6, G-6, Imaging: quality: the second grade.
f) the resolution power: about 0.12mm for C-CCD method, about 0.2mm for I-CCD, about 0.05mm for film method.

4. Examples of TNDRF

Neutron radiography has been used for NDT of some objects in SPRR-300 for a long period, for example: detecting parts including explosive, inspecting nuclear fuel elements, quality control of heavy metal component and so on.
Some neutron radiographs are shown below, and among these a, b, c and d are got by C-CCD imaging method, but f and g are got by film imaging method.

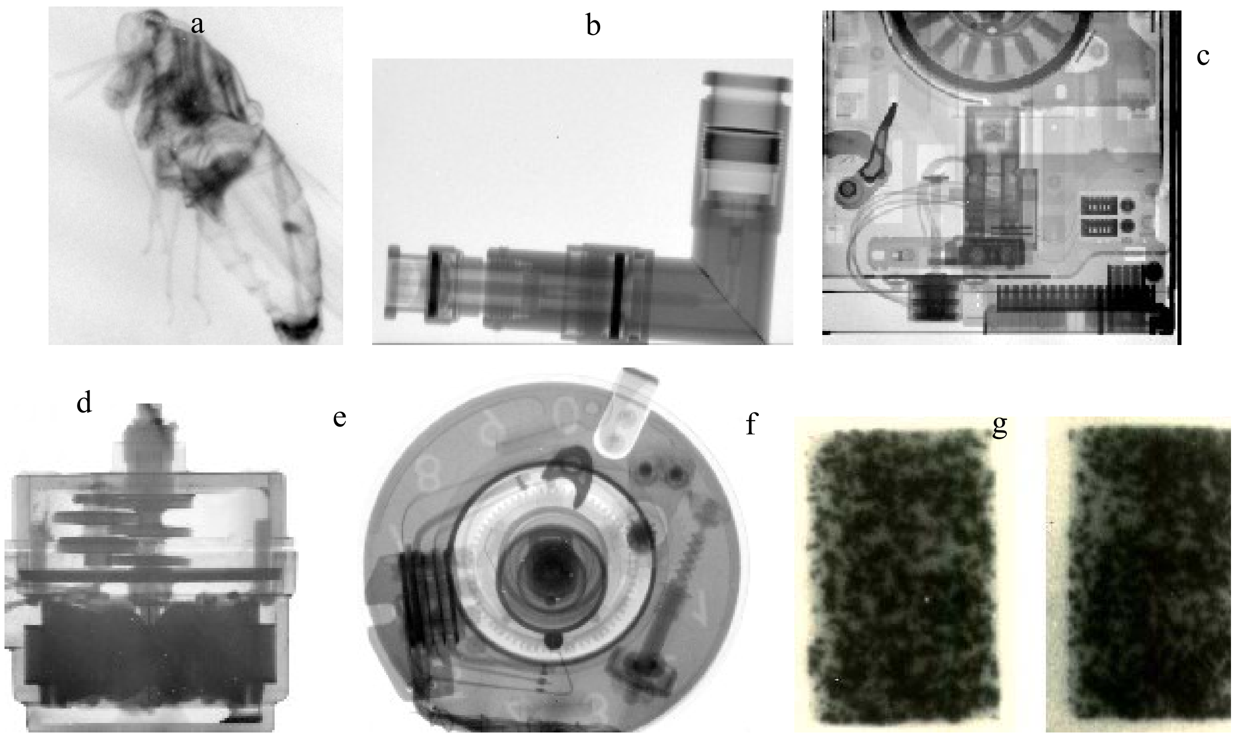

Fig 2 Some neutron radiographs got in SPRR-300. a: a cicada, b: a BNC connector, c: a floppy d: a motor, e: a telephone dial, f and g: UO_2 fuel pieces (a black dot is a Gd_2O_3 grain):

5. Discussion[4,5]

With the development of CCD technology, there are more and more neutron radiography facilities which use CCD method. However, there are two key questions which must be thought about. The first is how to improve further the resolution power of CCD imaging method to arrive at the level of film method if possible. The second is how to improve the ability of anti-irradiation of CCD to prolong CCD life and how to remove the white dots which are produced because of neutron and gamma irradiation to improve image quality. To resolve the first question, a small field of view (30×30mm^2) lens and a big array CCD chip (1024×1024 pixels) was used but the resolution power still need to improve comparing with film method. In order to resolve this problem, someone in China are trying to develop a new nanometer converter made of Dy or Gd crystal which maybe absorb a neutron to emit a light. To resolve the second question, an astronomy-grade CCD chip shall be used and shall be shielded severely against gamma and neutron irradiation, and a median filter arithmetic shall be used to reduce white dots.

6 Future Plan

TNDRF has some disadvantages because of various reasons, we will continually develop neutron radiography including neutron computer tomography and some new imaging methods (for example: neutron imaging plate and so on) to improve it. Presently, the use of neutron radiography is not quite universal in China because neutron sources are irremovable, expensive and so on, and neutron radiography is developed in few research institutes. But I think the status may be changed with the development of small removable neutron sources. We also wish to cooperate and exchange each other with all colleagues in the world!

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