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ScienceDirect

Physics Procedia 88 (2017) 175 – 183

Physics Procedia

8th International Topical Meeting on Neutron Radiography, Beijing, China, 4-8 September 2016

Thermal neutron radiography using a high-flux compact neutron generator

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Abstract

A novel neutron imaging system has been designed and constructed by Phoenix Nuclear Labs to investigate specimens when conventional X-ray imaging will not suffice. A first-generation electronic neutron generator is actively being used by the United States Army and is coupled with activation films for neutron radiography to inspect munitions and other critical defence and aerospace components. A second-generation system has been designed to increase the total neutron output from an upgraded gaseous deuterium target to 5×10^{11} DD n/s, generating higher neutron flux at the imaging plane and dramatically reducing interrogation time, while maintaining high spatial resolution and low geometric unsharpness. A description of the neutron generator and imaging system, including the beamline, target and detector platform, is given in this paper. State of the art neutron moderators, collimators and imaging detector components are also discussed in the context of increasing specimen throughput and optimizing image quality. Neutron radiographs captured with the neutron radiography system will be further compared against simulated images using the MCNP nuclear simulation code.

Peer-review under responsibility of the organizing committee of ITMNR-8

Keywords: neutron radiography; collimation; neutron detection; moderator; Mote Carlo, accelerator neutron source

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Peer-review under responsibility of the organizing committee of ITMNR-8
doi:10.1016/j.phpro.2017.06.024

1. Introduction

Recent years have shown neutron radiography to be a useful and complimentary tool for diagnostic imaging in NDT. While its usage has grown greatly from scientific curiosity to technological relevance, relatively little research and development has accompanied its growth (Harms 1986).

Due to the high atomic number of many materials to be routinely inspected including nuclear fuel pins, various munitions and critical aerospace components, X-ray imaging is often suboptimal. X-ray interrogation does a poor job in distinguishing spatial material composition information and introduces a high level of noise for dense materials. Neutron imaging can mitigate some of these challenges. Because neutrons interact with the nuclei of atoms in the specimen and not the electron cloud, they are much more effective at penetrating and providing compositional information about objects composed primarily of high Z materials. However, this technique comes with its own set of challenges for producing high resolution images within practical time periods. For this application, the use of thermal neutrons is preferred. The neutron energy spectrum coming from the often used TRIGA type reactor is inherently well thermalized where a large population of the neutrons have an energy below 0.4eV, which is typically desirable for neutron imaging. An accelerator-based D-D source requires complex moderator and collimator configurations to create a neutron beam with suitable properties for this application.

The electrostatic accelerator used to produce DD neutrons is shown in Figure 1. The source is deuterium gas, which is excited by high frequency microwaves to form a plasma. The D^+ plasma is then extracted and accelerated to 300 kV through a differential pumping system that produces a vacuum environment of 10^{-8}Torr (when the beam off), allowing for efficient beam transport. A typical beam current for this system is approximately 35 mA.

The target chamber, which is a water cooled stainless steel column, 1m long and 8 inches in diameter, is filled with deuterium gas at a pressure of 15 Torr. This pressure differential is made possible by narrow tube apertures that separate the upstream vacuum from the pressurized target. This narrow aperture induces a self-limiting condition of gas flow out of the target and so while some gas does escape, it is minimal, and is recycled by a series of roots blowers. Having a vacuumed accelerator column increases the total amount of deuterium ions that can reach the target without scattering from impurities in the accelerator while having a dense target increases the likelihood for the DD fusion reaction to produce 2.45 MeV neutrons. It is this unique design that allows for such a high neutron generation.

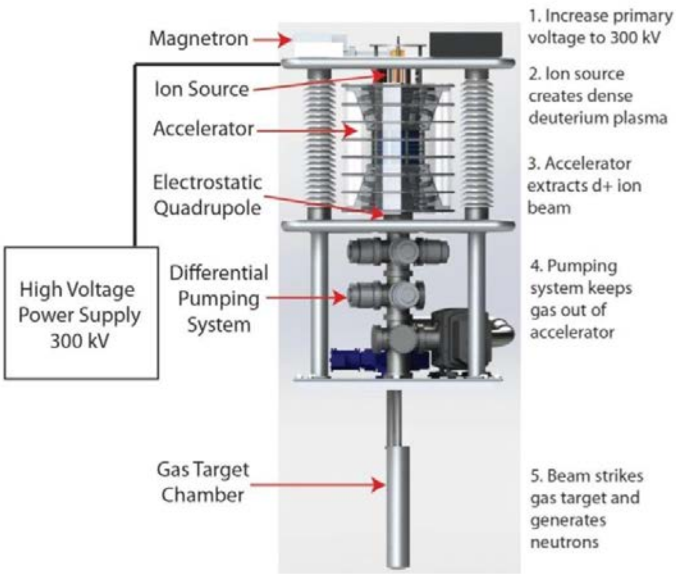

Figure 1. Left: photograph of the prototype deuterium LINAC. Right: schematic of the accelerator, differential pumping stages and target chamber.