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Neutron Radiography Tutorial

2010/07/23
MR10005

Introduction

This tutorial is intended to give a basic introduction to thermal neutron radiography. It does not describe the neutron source, collimation, safety, or moderation.

Neutron radiography is a non-destructive testing technique that is widely used in the nuclear and aerospace industries. It is similar to X-radiography insofar as both techniques use beams of penetrating radiation to interrogate an object, and generate an image that allows visualization of areas that attenuate the beam differently than neighbouring areas. However, neutrons are attenuated very differently than are X-rays, and therein lie the differences.

Neutron Attenuation

In simplified terms, neutrons are attenuated by matter either by scattering from the nucleus of a target atom or through absorption by that nucleus. Unlike X-rays, which interact predominantly with the electrons, there is no uniform increase in attenuation coefficient with atomic number. A plot of attenuation coefficient versus atomic number shows a nearly random structure. While clearer images are generated from samples where most of the attenuation is through absorption, meaningful neutron radiographs can be generated from scatterers as well.

Since neutron imaging is based on different attenuation properties than X-ray imaging, some elements that attenuate a larger number of X-rays, such as steel, or lead, will attenuate fairly small numbers of neutrons. Similarly, some elements that will attenuate a larger number of neutrons, such as boron or hydrogen, are low density materials that will attenuate fewer X-rays. The result is some objects near impossible to see with X-rays (a piece of paper in a glass container wrapped in lead foil) are easily visible with neutron images while other objects that are easily visible with X-rays (a steel component inside of a rubber or plastic housing) may be poorly imaged with neutrons.

Image Generation

Creation of images from the attenuated neutron beam can be accomplished in a variety of ways. The most frequently used method commercially is the direct method using X-ray film and a suitable conversion screen. Computed radiography (CR) and digital radiography (DR) are more frequently used in research applications. The conversion screen selected depends upon the application, but as neutrons are not easily detected, a layer of material to convert neutrons into a more easily detected form of radiation is generally required regardless of image capture method.

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Indirect or Transfer Method

When radioactive materials are being inspected, thin foils of either Dysprosium or Indium are generally used. These become radioactive in the neutron beam, mapping the neutron intensity incident on the foil. After being exposed sufficiently, the foils are removed from the beam and placed in close contact with an X-ray film. The radioactive decay of the foil causes exposure of the X-ray film. Subsequent development of the film yields a radiograph. Since the film is never exposed to the beam itself, this method yields pure neutron radiographs and can be used when the beam contains contaminating radiations such as gamma rays or when the samples are themselves radioactive. Computed radiography can also easily be performed with the indirect method, replacing the X-ray film with an image plate.

Direct Method

The direct method differs from the indirect method principally in that the image recording device is placed in the beam with the conversion screen. Therefore, decay of the conversion screen must occur quickly. Since the imaging device is exposed to the beam and to the sample, this method is not suitable for radioactive materials and cannot be used effectively when there are large amounts of contaminating radiation within the neutron beam. A commonly used conversion screen is a thin foil of gadolinium metal.

Track-Etch Imaging

If a plastic film in close contact with a material that yields heavy ions upon neutron absorption is exposed to a neutron beam, then the generated heavy ions will produce damage tracks in the plastic film. These damaged areas will be more easily dissolved than other areas. Thus, etching of the plastic with a suitable reagent (KOH for example) will yield damage pits. Under suitable lighting these pits will be rendered visible. A boron conversion screen is suitable, which emits alpha radiation when exposed to neutrons. The method is not frequently used.

Computed Radiography

Image plates appear and are used much like film. They are constructed from phosphors that contain defect points. Neutrons are converted to some form of ionizing radiation with a conversion material (commonly gadolinium). When ionizing radiation is incident on the plate it produces free electrons that are trapped at defect points in the phosphor. Since this will be proportional to the neutron intensity on the conversion material, the image is recorded in the image plate. The plate is then scanned by a laser in the device's reader. This provides the energy required to free electrons from the defect points. As the electrons fall back to the ground state, they emit visible light. This light is detected by a sensor, and so the image is read from the plate. The image can be displayed on a monitor. The image plates are cleared then reused.

Digital Radiography

Several different methods of producing neutron images digitally are grouped together under the title of digital radiography (DR). These systems capture the image with some form of digital detector array, a grid containing a large number of individual detectors that take a one-dimensional measurement of intensity at a single point. Since neutrons are generally challenging to detect, conversion of neutrons into some more easily measured form of radiation is required prior to detection. CCD camera based DR systems are one of the most common DR imaging systems, and these use a conversion material that will scintillate, converting neutrons into visible light. Mirrors and lenses transport the light to the CCD camera where the positional intensity is recorded over a period of time. One big advantage of DR systems is they allow images to be viewed in real time. This allows a image of a moving object to be produced, such as bubbles in a two phase fluid flow. Additionally, the production of an image without having to remove the imaging device from the beam line makes neutron tomography more practical.

Neutron Tomography

Neutron tomography is the construction of a three-dimensional image from a large number of two-dimensional images recorded with different known orientations. DR systems are by far the most suitable imaging method. An object to be imaged is loaded on a rotary table. Images are taken at a number of different angles and uploaded into a program that will use a mathematical algorithm to construct a three-dimensional image from the collection of two-dimensional images. The three-dimensional image can then be viewed as such, or dissected into two-dimension sliced views with any orientation through the object.