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Monte Carlo N-Particle Transport Performance of Predicting Digital Radiographic IQI Inspection

Dr. Vincent DiNova[1], Matthew Resz[1], and Benjamin Robinson[1]

[1]Savannah River National Laboratory
Savannah River Site, Aiken, SC 29808
(803)-679-7862; email me@vincent.dinova@srnl.doe.gov

ABSTRACT

The identification of porosity, geometric noncompliance, and other defect types are critical to the qualification of materials and components. X-ray radiographic nondestructive testing is a common industrial inspection method for process quality control and component qualification and certification. Digital radiography provides a quick and efficient alternative when compared to traditional film-based inspection. The quality of radiographic inspection is dependent on equipment specifications, such as the source spot size and detector pixel size, and the specific parameters selected for use for the radiographic technique. To evaluate if an x-ray system and technique is sufficient for a given requirement, a radiographic image quality indicator (IQI) can be used. Radiographic IQIs in hard to machine materials or hard to manufacture defects can be time consuming and expensive to manufacture. This study was conducted to evaluate current Savannah River National Laboratory (SRNL) x-ray imaging systems with a custom tantalum IQI and using Monte Carlo simulations to predict the performance of future systems. The tantalum IQI was tested using a Siefert Isovolt 420 keV x-ray tube with a Perkin Elmer XRD 1611 flat panel with 100-micron pixels. Using the Monte Carlo N-Particle transport software, the radiographic tally was used to simulate the photon flux through an identical tantalum IQI. These simulations provided a benchmark as to the best theoretical identification on a given system using our tantalum IQI. The simulations were refined to match SRNL's current systems' noise levels, leading to confidence in their ability to predict the performance of other systems that may be purchased and deployed in the future at the Savannah River Site. Future studies will be conducted to prove this research can be extended to artificially evaluate the ability for systems to identify critical defect sizes through x-ray radiographic inspection, drastically reducing the cost and time burdens of producing high-fidelity radiographic test articles.

Keywords: non-destructive testing; digital X-ray radiography; image quality indicators; MCNP

Introduction

Following the manufacturing of industrial materials or components, nondestructive evaluation techniques are often deployed to evaluate the resulting quality without causing damage to the final product. One evaluation technique that can be used for nondestructive defect detection is X-ray Digital Radiography (DR) [1]. X-ray DR involves an x-ray source, either an x-ray generating device or a radioisotope source, to generate photons that are attenuated through an object and detected by a flat panel imager. Since x-rays are capable of fully penetrating most materials and components, x-ray DR is one of the few inspection technologies that can detect defects through an entire volume. Defects can be obfuscated; however, through low image quality with improper radiography techniques or low signal to noise challenges, such as high density or thick materials or components. Image quality needs to be assessed prior to defect detection in digital radiography to ensure critical flaws or defects can be properly identified by the system and technique being deployed [2]. Various standards published by the American Society for Testing and Materials (ASTM) have been created for assessing radiographic image quality using either image quality indicators (IQIs) or representative quality indicators (RQIs) [3-5]. Image quality indicators for difficult to machine materials or for difficult to manufacture defects can be expensive and time consuming to design and fabricate. Monte Carlo N-Particle transport-based simulation software [6] has been used to simulate neutron digital radiography image quality indicators [7]. The intent of this study is to determine if a defect will be able to be detected with a x-ray system and technique through the use of MCNP.

Materials and Methods

The motivation of this study is to determine if a Seifert Isovolt 420/10 x-ray tube with a Perkin Elmer XRD 1611 flat panel is sufficient to inspect and identify each feature in a custom 5 x 7 radiographic IQI. The IQI manufactured and used in this study was a 3 mm thick Tantalum plate with a pattern of holes arranged in 5 columns and 7 rows with varying depth and width. The diameter for each hole ranges from 0.2 mm to 5 mm at depths spanning from 0.05mm to 0.4 mm. Due to the size and material of the IQI, the holes were manufactured by OpTek using a blind laser, Figure 1.

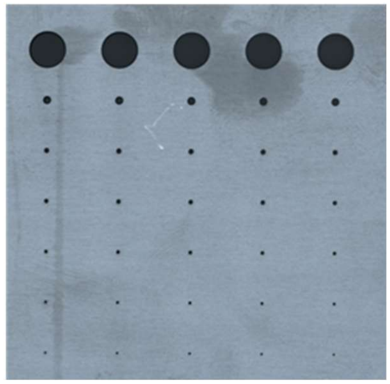

Figure 1: Photograph of Tantalum 5 x 7 Radiographic Image Quality Indicator

A Keyence VR-5000 was used to accurately measure the manufactured diameter and depth of the holes made by the laser, in addition to the edge surface profile, Figure 2. In Table 1, a collection of the measured diameters was recorded. The largest 2 holes were identified as having consistent and accurate diameters to the specifications; however, the constraints of the hole sizes became too difficult for the manufacturing process to achieve. Additionally, the depth profiles of the holes identified that the edges were rounded, and the profile of bottom of the holes were not flat.

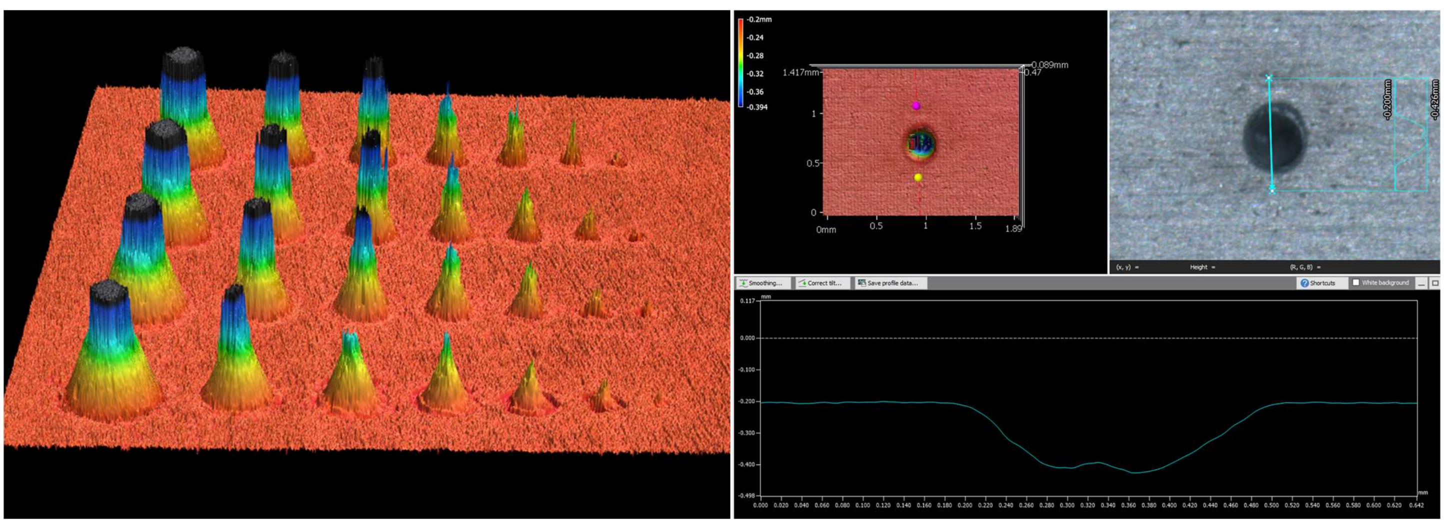

Figure 2. Keyence Hole inspection of 5 x 7 Radiographic Image Quality Indicator

Table 1: Radiographic IQI Measured Hole Diameters (mm)

Target Diameter	Measured Diameter Column 1	Measured Diameter Column 2	Measured Diameter Column 3	Measured Diameter Column 4	Measured Diameter Column 5
5.0	5.077	5.073	5.071	5.078	5.078
1.0	1.080	1.077	1.102	1.100	1.081
0.5	0.682	0.703	0.713	0.705	0.683
0.4	0.586	0.604	0.614	0.603	0.584
0.3	0.484	0.513	0.515	0.511	0.484
0.2	0.387	0.409	0.409	0.409	0.365
0.1	0.282	0.307	0.311	0.310	0.281

Digital Radiography Testing Technique

The Radiography IQI was inspected using the Seifert Isovolt 420 keV x-ray tube with the 3mm spot size at 2mA with a 5 second exposure and 32 frame averaging. A lead collimator was used to block the x-ray beam from saturating the rest of the panel, Figure 3. The IQI was placed directly against the Perkin Elmer 1611 flat panel to reduce cone beam effects and geometric unsharpness.

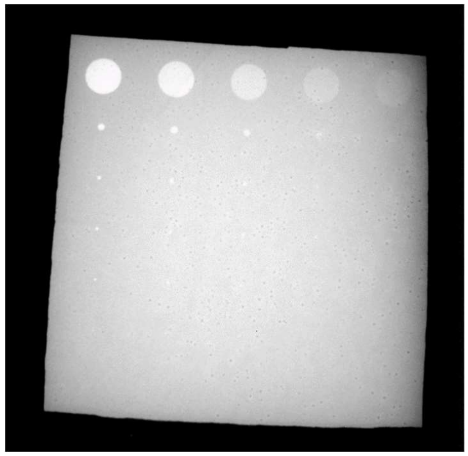

Figure 3. Radiograph of 5x7 Radiography IQI

MCNP Simulation

To simulate the x-ray spectrum of our x-ray imaging system, 420 keV electrons were simulated to impact a tungsten target in MCNP. A F2 tally was used to generate the energy spectrum of the secondary photons leaving the target's surface. The resulting photon energy spectrum was then used as the source definition of a Fir5:p radiography tally with the tantalum 5 x7 Radiography IQI placed in the upper left hand side of a theoretical detector, Figure 4. The flux of the radiography tally was then normalized to a emulate the output of 16-bit flat panel imager. The average background measured in dark images of the background radiographs were then added using ImageJ [8], Figure 5.

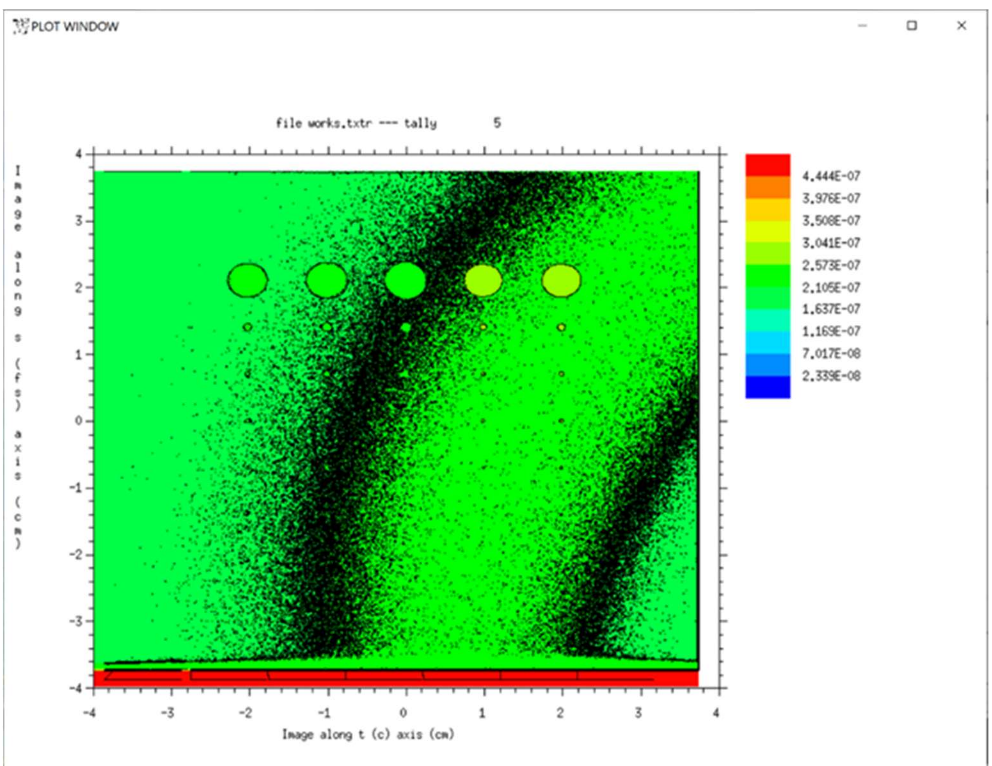

Figure 4. MCNP Fir5:p Tally of 5x7 Radiography IQI

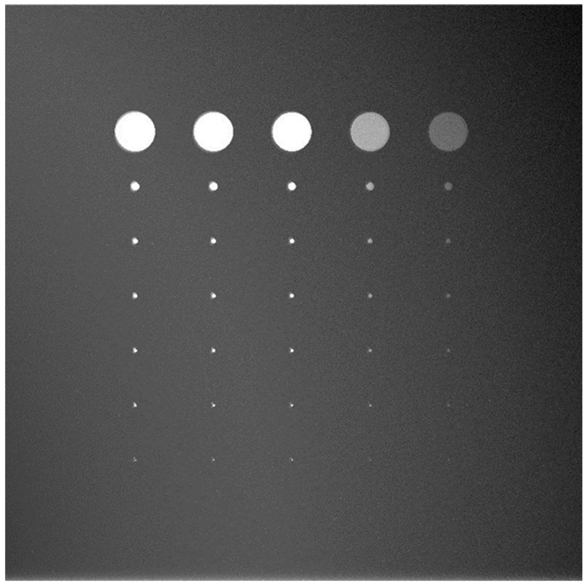

Figure 5. Simulated Radiograph of 5 x 7 Radiography IQI in ImageJ

Discussion and Conclusions

The findings from the Keyence VR-5000 measurements identified the need to manufacture more accurate IQIs. The measurements of the depth and diameters, along with the resulting profiles, make direct comparisons to the simulations challenging to directly model. The simulations revealed that each of the 35 holes are identifiable with the equipment used, even with the IQI placed outside of the center of the beam, compared to the 29 holes identified with our x-ray imaging system and at the beam centerline. Further refinement of the noise and background levels will be investigated to predict the radiographic results more accurately, as well as testing on different x-ray imaging systems and equipment.

Acknowledgments

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Presenting Author Biography

Dr. Vincent Dinova is a Senior Engineer in the Instrumentation, Robotics, and Imaging Systems group at Savannah River National Laboratory (SRNL). Vincent joined SRNL in 2020 and has researched X-Ray imaging techniques, simulations, and on qualification processes for additively manufactured components.

Presentation Short Description

A study was conducted to evaluate current x-ray imaging systems using a custom tantalum IQI and Monte Carlo simulations to predict the performance of future systems. Using the Monte Carlo N-Particle transport software, the radiographic tally was used to simulate the photon flux through an identical tantalum IQI for comparison.