Applied Radiation and Isotopes 107 (2016) 24–28

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Design and testing of an anti-scattering grid for medium-energy X-ray flash radiography

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HIGHLIGHTS

- We design an anti-scattering grid used in medium-energy X-ray flash radiography.
- We perform Monte Carlo simulations to optimize the parameters of the grid.
- The grid for testing is produced by precision mechanical drilling technology.
- High-quality image with good resolution is obtained after using the as-designed grid.
- The as-designed grid is very thin and can be easily produced.

ARTICLE INFO

Article history:
Received 25 April 2015
Received in revised form
28 August 2015
Accepted 4 September 2015
Available online 8 September 2015

Keywords:
X-ray flash radiography
Medium energy
Anti-scattering grid

ABSTRACT

We propose an effective design of a 2-mm-thick tungsten anti-scattering grid for medium-energy X-ray imaging. First, the Monte Carlo simulation is carried out firstly, which indicates that the ratio of direct to scattered radiation can reach as high as 1.54. The grid for the testing is produced using precision mechanical drilling technology, with the typical size of 52.1×52.1 mm^2. Clear edge of the sample can be visualized in the image when the designed grid is used and the quality of the image is substantively improved.

1. Introduction

X-ray flash radiography is one of the great inventions of the past century and it allows one to detect the interior of objects. At present, the X-ray imaging technique is widely used in a variety of applications such as medical diagnostics, nondestructive testing, airport security, and industry computed tomography (CT). Particularly, high-energy X-ray flash radiography was developed during the Manhattan project in Los Alamos to provide quantitative density information for the compressed heavy metal surrogate in hydro-test experiments to aid in the design of new weapon systems (Harsh et al., 2010; Morris et al., 2011; Watson, 1996, 2005; Watson et al., 1999). High-quality imaging with good resolution is of utmost importance in all these applications.

Among various factors, the scatter background is the most crucial one that affects the quality of imaging (Fahrig et al., 1994). Without any intervention, both the scattered and primary radiations from the samples are recorded by the image-recording device (Tang et al., 1998). Subject contrast and the signal-to-noise ratio in the image are reduced, and the details of the information cannot be obtained, which are unfavorable for the following analysis. At present, the anti-scattering grid is the most commonly used method to reduce the scatter noise, which was introduced by Bucky (1915). In principle, some metal plates with a large number of holes focused toward the X-ray source will only allow the direct rays to pass through to the detector, but absorb the scattered radiation with random orientation (Tang et al., 1998). Recently, several studies of the grid have been focusing on their manufacturing techniques, geometric studies, and structure design, particularly at lower X-ray energies for medical detection (Coleman et al., 2000; Guckel et al., 1994; Kafi et al., 2009; Lehmann and Ronnebeck, 2001; Makarova et al., 2008; Tang et al., 1998, 2001, 2008; Tromans et al., 2010). Watson's group also successfully designed and fabricated a large anti-scattering grid for high-energy flash radiography at the Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) in Los Alamos (Harsh et al., 2010; Watson et al., 2005). Because of the difference in energy, the design of the grid is different (Tang et al., 1998; Watson et al., 2005).

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http://dx.doi.org/10.1016/j.apradiso.2015.09.003
0969-8043/

However, there has been no study so far reporting the use of anti-scattering grid by the medium X-ray energy. In this region, flash radiography or X-ray imaging technique is used both in industry CT and in the study of expansion and fracture of the metal shell (Gold and Baker, 2008; Li et al., 2009; Tang et al., 2008). In the second case, an object with high strength is always set as a shield to prevent the fragments from damaging the image recording device, and this will cause a serious scatter background. Obtaining a high-resolution image is also a matter of concern. Hence a good design of the anti-scattering grid to reduce the scatter noise has to be developed.

In this study, an unfocused tungsten anti-scattering grid with parallel walls, which could be used in medium X-ray energy flash radiography, was designed. The parameters of the grid were optimized by Monte Carlo simulation. The diameter of each hole was 1.1 mm, and the distance between the centers of two nearest holes was 1.5 mm. The grid for the test was produced using precision mechanical drilling technology, with the typical size of 52.1 $\times$ 52.1 mm^2 and thickness of 2 mm. The proof testing of the grid was performed with a Scandiflash 450s X-ray source. The result showed that the scatter background was effectively reduced by 3.5 times when the anti-scattering grid was applied.

2. Experiments and results

Because the design of the anti-scattering grid should adapt to experimental conditions, it is evident that the parameters of the grid would change depending on the experimental setup. In our experiment, we used a Scandiflash 450s flash radiographic source (100 keV X-ray energy, 25 ns pulse, 25 mR at 1 m). According to these source parameters, the experimental setup is shown in Fig. 1. Our scattering test object consisted of a 10-mm-radius cavity void surrounded by a 40-mm-radius aluminum sphere, which in turn was surrounded by a 60-mm-radius poly(methyl methacrylate) (PMMA) sphere. The object was placed on a PMMA support with its center approximately 500 mm downstream from the bremsstrahlung source. The image-recording device used in the process was common photographic film, which was 597 mm from the source, and the anti-scattering grid was placed in front of it. An aluminum plate was also placed in front of the grid as the fragment's shield. The detailed setup can be seen in Fig. 1(b). The centers of all these devices lie on the axis of the X-ray source.

On the basis of the above-described experimental setup, we began to design the anti-scattering grid. As this grid was employed in the medium-energy region, large Z materials should be used. Light-weight metals used in lower energy could not meet the requirement. Therefore, tungsten alloy with a density of 17.1 g/cm^3 was chosen. According to the principle of designing grid, the thickness should be such that the ratio of the scattering X-ray intensity after and before the grid is $<10^{-8}$. According to the Beer–Lambert rule, $I = I_0 \exp(-\mu_l l)$, where I and I_0 are the intensities of the X-ray before and after the grid, respectively, and μ_l is the linear absorption coefficient (μ_l=85.5 based on the X-ray source used), l, the thickness of the grid, could be determined (Harsh et al., 2010; Watson, 2005). In this study, the thickness of the grid was set at 2 mm, which could meet the requirement. Because the grid was very thin, an unfocused-type grid may also be feasible.

The hole diameter and the distance between two nearest holes were also important parameters of the anti-scattering grid. If the holes were too big and the distances between them were too short, the scattering radiation cannot be effectively prevented. On the contrary, the direct ray would also be absorbed at the same time. Therefore, choosing appropriate values for the parameters was necessary. In this work, we used the transmission to weigh the capability of the grid. In order to reduce the difficulty of manufacture, the grid was set as a square, with all the holes aligned in parallel. Then the transmission of the grid R could be written as $R = \frac{n \cdot \pi d^2}{4a^2} \times 100\%$, where n is the number of holes, d is the hole diameter, and a is the size of the grid. According to the experimental setup, the size could be determined as 52.1 $\times$ 52.1 mm^2. As it was a square, the number of holes n could be expressed by using a and the distance between two nearest holes s, written as $n = (\frac{a}{s} + 1)^2$. Substituting this into the function of R, the expression of R with the hole diameter and the distance could be obtained as $R = \frac{\pi d^2}{4a^2}(\frac{a}{s} + 1)^2$. Using this formula and self-built Monte Carlo codes (Liu et al., 2004, 2011), we finally determined the hole diameter and the distance between the holes as 1.1 and 1.5 mm, respectively, and the transmission could reach 42%, which was similar to the capacity of the grid used at the DARHT in Los Alamos (Watson et al., 2005). The optimized parameters were determined, as shown in Table 1.

With these geometry parameters, a Monte Carlo simulation was performed to compare the cases with and without the

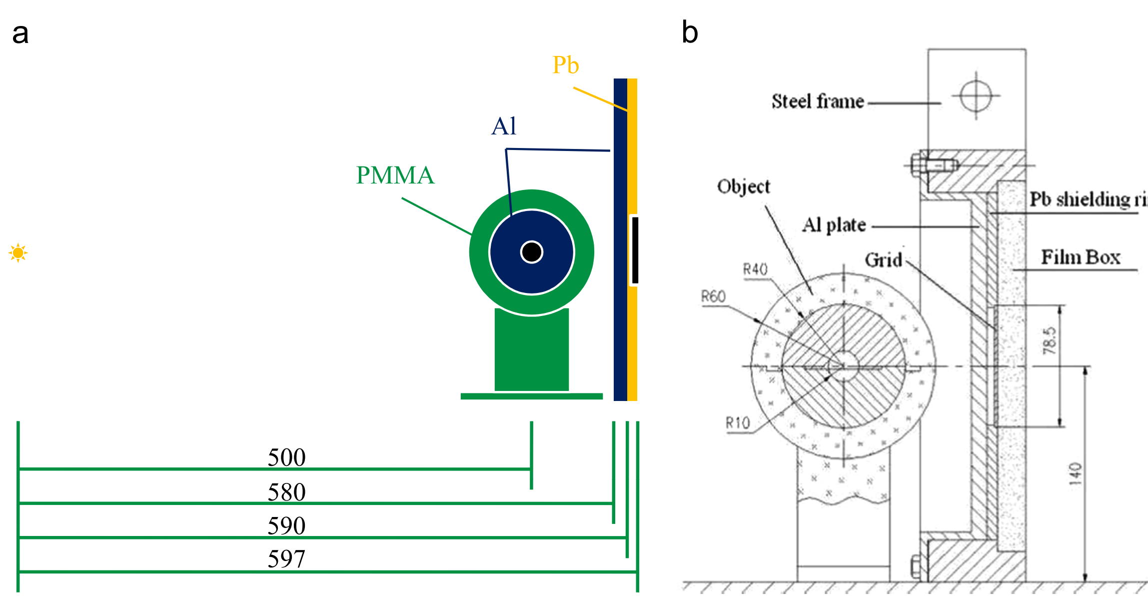

Fig. 1. (a) Schematic of the experimental setup; (b) detailed structure of the test object and the image-recording device.