Reconstruction of High-energy X-ray Source Using L-Cylinder Imaging Device

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***Abstract*—The L-Edge and L-Cylinder imaging devices are used to reconstruction the image of high-energy X-ray source. The physical model considering the penetration effect of X-ray to the imaging device is established, the transmission imaging matrix is constructed, and the algebraic solution method of spot image reconstruction is established. The X-ray source with Gaussian distribution is reconstructed The results show that the artifacts and discontinuous in the center of the reconstructed images can be improved using L-Cylinder imaging device.**

***Index Terms*—reconstruction, X-ray source, L-Cylinder**

I. Introduction

The blur caused by the high energy X-ray source spot is one of the important factors leading to image degradation. Focal spot measurement is an important part of studying high-energy X-ray flash radiography. The major laboratories engaged in the research of high-energy X-ray flash radiography at home and abroad have carried out the related research on spot size measurement, and representative methods include pinhole method, slit method, edge method, rollbar method and so on.

In 2016, Fowler et al. [1] designed the L-Rolled Edge device for imaging based on the "opaque" physical model of the imaging device proposed by Barnea [2], using only one corner of the square hole imaging device, obtained the imaging light and shade information of two dimensions, and gave the two-dimensional intensity distribution of focal spot through image reconstruction. In this paper, based on the "L" configuration device, an imaging physical model considering transmission effect is proposed, and L-Cylinder imaging device is used to reconstruct the X-ray source image. The two-dimensional distribution of the source penetrating the imaging device is obtained, and the intensity distribution of the source is derived by image reconstruction.

An outline of the rest of the paper is as follows. In Section 2, We present the physical model and solution method. Numerical results for reconstruction using L-Cylinder imaging device are presented in Section 3. Finally, the conclusion are summarized in Section 4.

II. Physical Model and Solution Method

It is assumed that the X-ray source is an ideal source, that is, an isotropic monomeric point source. The intensity of X-rays emitted from the source, passing through the object and reaching each point on the detector plane can be expressed as

$$I(x,y) = I_0(x,y)e^{-L(x,y)} = I_0(x,y)e^{-\int_0^{d(x,y)}\mu(l)dl}, \quad (1)$$

where $I(x,y)$ and $I_0(x,y)$ are the intensity of X-rays received by the detector with or without objects, $L(x,y)$ is the total optical path of the X-rays to point (x,y) on the imaging plane, $d(x,y)$ is the distance from the point (x,y) on the imaging plane to the source, and $\mu(l)$ is the linear attenuation coefficient of X-rays in the material at a distance l from the source.

If the source plane and the imaging plane are respectively discretized in pixels and regarded as one-dimensional vectors, the formula 1 can be written in the form of matrix multiplied by vector:

$$\boldsymbol{A}\boldsymbol{x} = \boldsymbol{b}, \quad (2)$$

where $\boldsymbol{b}$ is the measurement vector, $\boldsymbol{x}$ is the reconstructed image vector, and $\boldsymbol{A}$ is the projection matrix of size $M \times N$. The element a_{ij} of matrix $\boldsymbol{A}$reflects the overall attenuation of the i-th source intensity reaching the j-th pixel in the imaging plane after passing through the imaging device. In practice, if noise generally exists, the above formula becomes

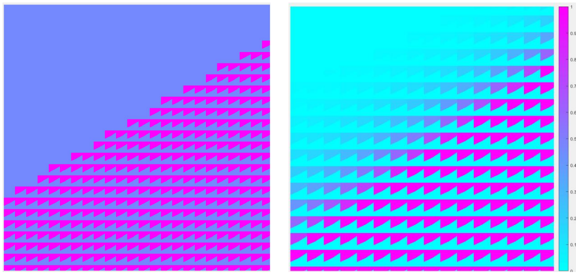
$$\boldsymbol{A}\boldsymbol{x} = \boldsymbol{b} + \boldsymbol{n}, \quad (3)$$

where $\boldsymbol{n}$ is the noise of the imaging system.

It is assumed that the source is 15cm away from the center of L-Edge and the imaging plane is 120cm away from the center of L-Edge, that is, the geometric magnification ratio M of the imaging system is 8. Assuming that the L-Edge imaging device is a homogeneous single medium, the element a_{ij} of the imaging matrix based on the transmission model can be written as

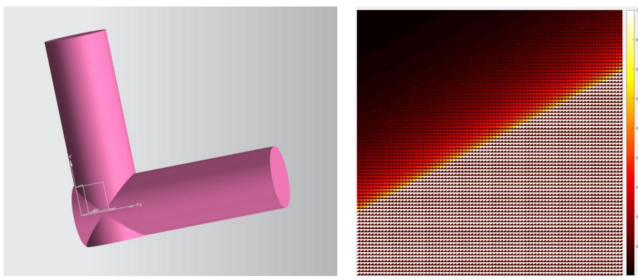
$$a_{ij} = I_0 e^{-L((x',y')\to(x,y))} \quad (4)$$

where $L((x',y') \to (x,y))$ is the optical path of X-rays passing through the L-Edge imaging device on the path from point (x',y') in the source plane to point (x,y) in the imaging plane. It can be derived according to the geometric relative position relationship.



(a) (b)

Fig. 1. Imaging matrix of L-Edge imaging device with different physical models (local enlargement). (a) Opaque model; (b) Transmission model considering transmission effect.



(a) (b)

Fig. 2. (a) L-Cylinder imaging device; (b) The transmission imaging matrix of the L-Cylinder device.

For the ”opaque” model adopted by Barnea et al. [2], it is equivalent to μ being infinity, and the matrix element based on the ”opaque” model can be written as:

$$a_{ij} = \begin{cases} 1, & L > 0, \\ 0, & L = 0. \end{cases} \quad (5)$$

Figure 1 shows the imaging matrix of these two models under the same imaging state. It can be seen that the transition between light and shade of opaque model is simple, see Figure 1(a), whereas the imaging matrix in Figure 1(b) changes gradually after considering the transmission effect, which can more truly reflect the gradual change of X-ray intensity when penetrating L-Edge imaging device.

III. Reconstruction of Source

In view of the right angle edge of L-Edge imaging device, there is a sudden change of image intensity near the edge, which leads to serious artifacts in the reconstructed image [3]. Therefore, we propose an improved design, that is, the L-Cylinder imaging device is directly formed by splicing two sections of cylinders into an ”L” shape, as shown in Figure 2(a). The transmission imaging matrix of the constructed L-Cylinder device is shown in Figure 2(b). The transmission imaging matrix based on the improved imaging device can form a uniform band transition region, which is beneficial to the smoothness of the reconstructed image theoretically.

Set the FWHM of X-ray source with Gaussian distribution used in the Monte Carlo simulation as 0.2 cm. Figure 3 shows the MC photographic image of this source and its reconstructed intensity distribution, and the cross-sectional lines of the reconstructed image in different directions are shown in Figure 4 [4].

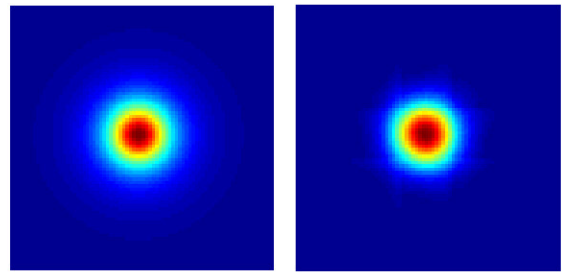


Fig. 3. Ground truth and reconstruction of Gaussian Source. Left: Ground truth; Right: Reconstruction with L-Cylinder device.

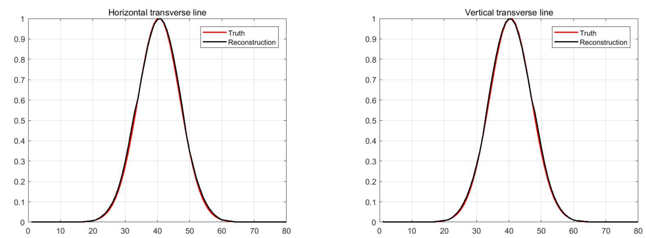


Fig. 4. Transverse lines of reconstructed source in horizontal and vertical directions.

As can be seen from Figure 4, the L-Cylinder imaging device can well reconstruct the intensity distribution of Gaussian source, and accurately measure the FWHM of Gaussian source to be 0.2cm. The L-Cylinder imaging device significantly improves the discontinuity phenomenon which reconstructed with L-Edge imaging device.

IV. Conclusion

In this paper, the spot measurement method of high-energy X-ray source based on image reconstruction is studied. The physical model considering the penetration effect of X-ray to the imaging device is established, and the algebraic solution method of spot image reconstruction is established. The X-ray source with Gaussian distribution is reconstructed. The results show that the artifacts and discontinuous in the center of the reconstructed images can be improved using L-Cylinder imaging device, and is more suitable for the reconstruction of high-energy X-ray source.

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