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Spot size diagnostics for flash radiographic X-ray sources at LAPA *

LI Cheng-Gang(李成刚)1) LI Qin(李勤) SHI Jin-Shui(石金水) DENG Jian-Jun(邓建军)

(Laboratory of Accelerator Physics and Application, Institute of Fluid Physics, CAEP, Mianyang 621900, China)

Abstract Spot size is one of the parameters to characterize the performance of a radiographic X-ray source. It determines the degree of blurring due to magnification directly. In recent years, a variety of measurement methods have been used to diagnose X-ray spot size at Laboratory of Accelerator Physics and Application (LAPA). Computer simulations and experiments showed that using a rolled-edge to measure the spot size are more accurate, and the intensity distribution of X-ray source was obtained by a device with a square aperture. Experimental and simulation results on a flash X-ray source at our laboratory are presented and discussed in this paper. In addition, a new method for time resolved diagnostics of X-ray spot size is introduced too.

Key words linear induction accelerator, X-ray spot size, rolled-edge, square aperture, time resolved, Dragon-I

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1 Introduction

Since 1990s considerable work has been done at LAPA for the purpose of creating high-brightness, high-dose flash radiographic X-ray sources. Two linear induction accelerators(LIA), 12 MeV LIA[1] and Dragon-I[2], have been constructed successively. In both of them, high energy, high current, small spot electron beams are generated, and focused on high Z targets (typically tantalum or tungsten), producing bremsstrahlung X-ray radiation. As one of the major parameters, the spot size not only helps characterize the X-ray source performance, which is used for final tuning of accelerators, but also provides a figure of merit to assess the suitability of various sources to specific experimental requirements.

A typical spot size diagnostic setup is shown in Fig. 1. An opaque object is located between a radiographic X-ray source and a detector. Different opaque objects lead to different diagnostic methods. Ordinary pinhole methods use a tungsten cylinder with a small hole; thin slit diagnostic[3] setup consists of two thick tungsten cuboid blocks and a thin (about 1 mm) low-density material layer between the two blocks; rolled-edged method[4] uses a cylindrical segment of tungsten, while square aperture setup[5] uses a tungsten alloy block with a wide square aperture. The spot size is obtained by dealing with the penumbral shadow distribution on the detector.

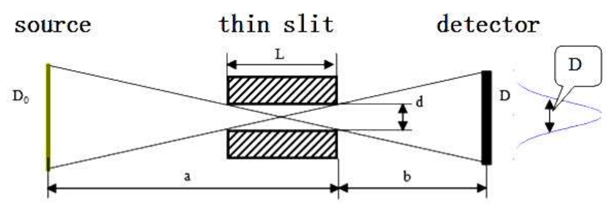

Fig. 1. The sketch of spot size diagnostic.

The detector is optional. Typically a radiographic film is used for a time integrated measurement, while a scintillator is used to convert the X-rays to visible photons which can be imaged by using a gated camera for time resolved X-ray spot size diagnosis.

Diversified simulations and experiments have been done for spot size diagnostic. Several of them are presented in this paper.

2 Computer simulation

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1) E-mail: lcg_bit@caep.ac.cn

energy, angle of electron incidence, and target material. Clearly such complexity is incompatible with a simple model, so we assume an isotropic 2D distribution X-ray source, and consider it independent of time. Moreover, we divided the source into numerous point sources, each having a corresponding intensity. A Simulation is calculated by assuming a photon takes a straight line geometric path from an ideal point source and is attenuated by the opaque object exponentially, $I = I_0 \times \exp(-\mu \times x)$, where x is the amount of high density material that the X-ray photon passes through, and μ is the 4 MeV extinction coefficient, taken as 75.9 m^{-1} for tungsten. This ignores any scattering effects.

Thin slit diagnostic setup is shown in Fig. 1. Assuming the source is Gaussian and the spot size (FWHM) is varied from 0.5 mm to 4.5 mm, where $a = 2085$ mm, $b = 2790$ mm, $d = 0.96$ mm, and $L = 200$ mm. Using Matlab a simple code was developed to simulate the image produced by the measurement device. Meanwhile, according to the geometry of the measurement device, a simple calculation equation[1] $D_0 = [Da - d(a+b)]/b$ was used to estimate the spot sizes. Fig. 2 shows both the results of simulation and calculation, which shows a far difference. Because it is assumed that the source intensity distribution is a uniform circle when the equation is given. However, in simulation the Gaussian distribution was used.

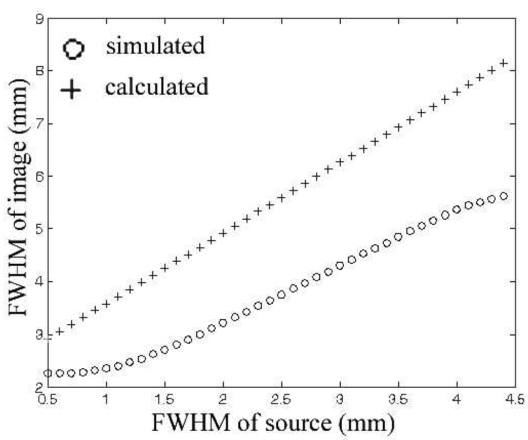

Fig. 2. Thin slit diagnostic simulation.

The square aperture diagnostic was also simulated. First, we assumed a two-peak X-ray source (Fig. 3). And then a penumbral shadow distribution (Fig. 4) was received in the detector plane. Using a Matlab code we decoded the penumbral image and obtained a reconstructed source (Fig. 5) at last. In our example, the aperture's width is 10 mm and its thickness is 120 mm. The distance from the source to the rear-end of the aperture is 1m and the distance from the rear-end of the aperture to the detector is 2m. As we can see from Fig. 3 and Fig. 5, the shape of the reconstructed source is the same as that of the original one, and the spot size is comparable. Actually, there is 15% size difference between the two sources.

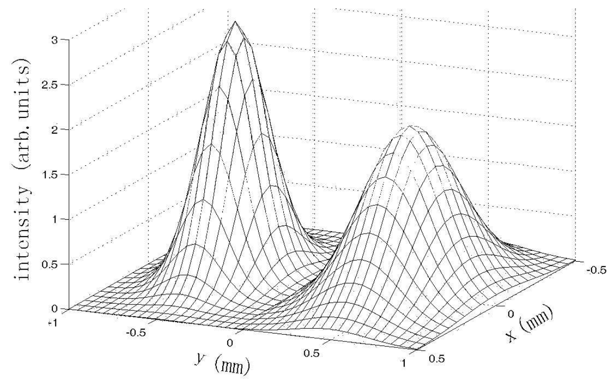

Fig. 3. The original two-peak X-ray source.

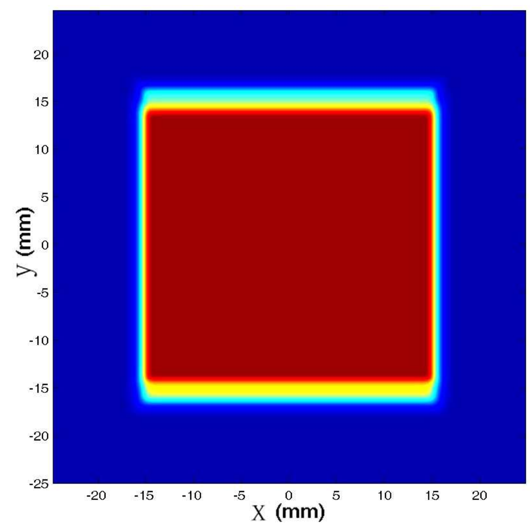

Fig. 4. The raw data form CCD camera.

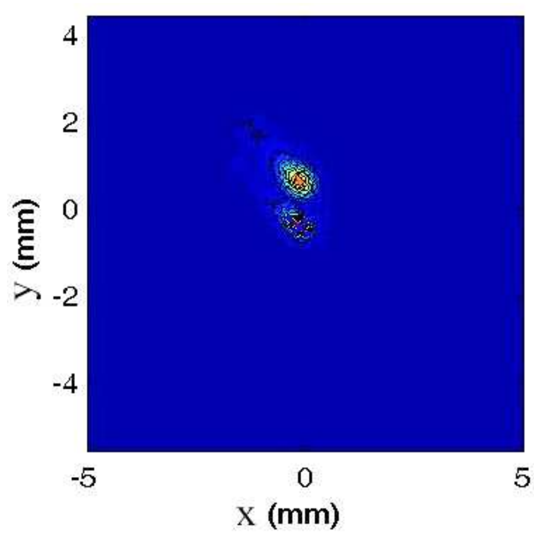

Fig. 5. The reconstructed two-peak X-ray source.

The rolled-edge diagnostic was also simulated. Assuming the sources are Gaussian and the original spot sizes vary from 0.5 mm to 2.4 mm, the reconstructed source data are shown in Fig. 6. The error is less than 7.4%.

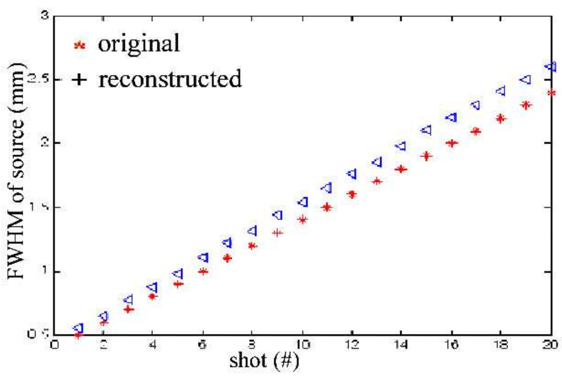

Fig. 6. The rolled-edge diagnostic simulation.

3 Experimental results on Dragon-I

The square aperture diagnostic technique was applied to measure the source intensity distribution on Dragon-I. The substrate of the aperture is made of lead, the width of the aperture is 10 mm and its thickness is 120 mm. The aperture is imaged onto a 10 mm C_SI scintillator screen. The distance from the source plane to the rear-end of the aperture is 2 m and the distance from the rear-end of aperture to the screen is 2.8 m. the screen is divided into 1252×1152 pixels, and the size of each pixel is 0.122 mm. The image of raw data is shown in Fig. 7, and the reconstructed image is shown in Fig. 8. The equivalent spot size is FWHM = 2.60 mm.

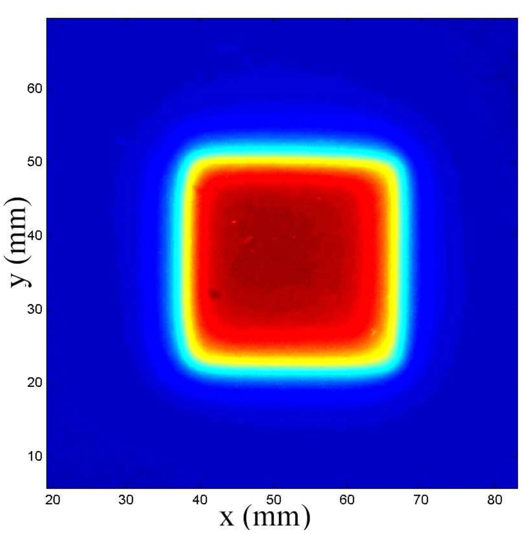

Fig. 7. The raw experimental data.

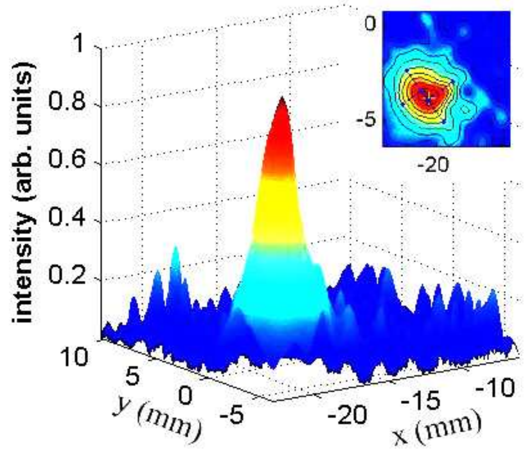

Fig. 8. The reconstructed source.

The rolled-edge diagnostic technique was applied to measure the spot size on Dragon-I. The rolled-edge is made of a small segment of tungsten cylinder with a radius of 1 m, and the detector is the same as the former setup. The magnification is 3.08. The raw data are shown in Fig. 9, and the rectangle field is chosen for spot size. The rolled-edge data (ESF) and differentiated data (LSF) are plotted in Fig. 10, and the modulation transfer function is shown in Fig. 11. The equivalent spot size is FWHM = 2.55 mm.

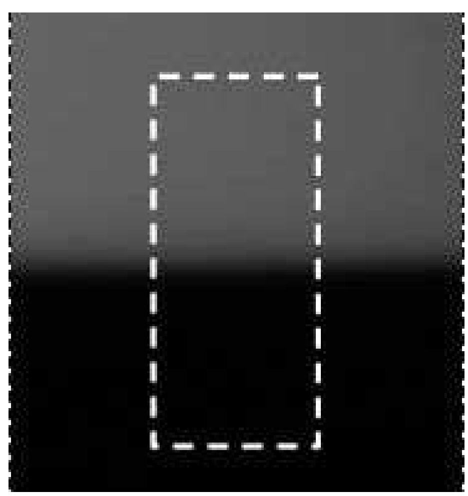

Fig. 9. The raw rolled-edge data.

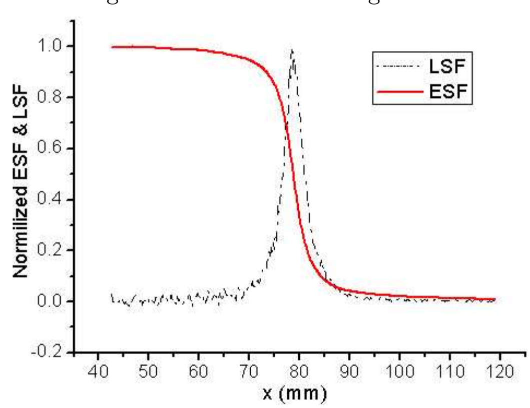

Fig. 10. The rolled-edge data and differentiated data.

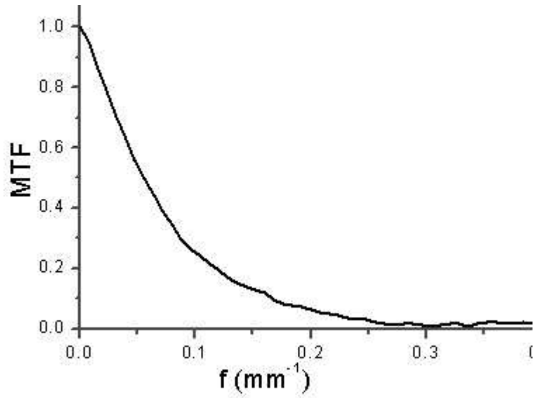

Fig. 11. The modulation transfer function.

4 Time resolved diagnostic

Time resolved diagnostic is also developed at LAPA, the setup is shown in Fig. 12. LYSO, a special crystal, is used as scintillator.

Using a 10 ns gated camera, during one shot we obtained successive 8 images, which were used to obtain the time-resolved spot sizes. They are 1.8, 2.1, 1.7, 1.6, 1.8, 1.5, 1.7, and 1.8 mm.

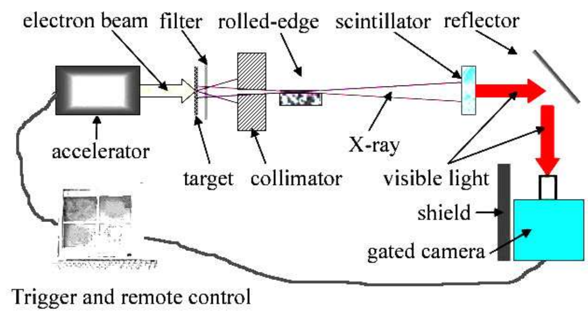

Fig. 12. The time resolved spot size diagnostic.

5 Conclusions

Simulation and experimental results of different spot size diagnostics have been presented. Rolled-edge and square aperture are verified, while thin slit diagnostic is not fit for Gaussian distribution. In addition, the initial results of time resolved diagnostic are obtained.

References

1 SHI Jin-Shui, DING Bo-Nan, DENG Jian-Jun et al. High Power Laser and Particle Beams, 1997, **8**(4): 599—603 (in Chinese)

2 DENG Jian-Jun, DING Bo-Nan, WANG Hua-Cen et al. High Power Laser and Particle Beams, 2003, **15**(5): 502—504 (in Chinese)

3 SHI Jin-Shui, LI Jin, HE Yi et al. High Power Laser and Particle Beams, 1999, **11**(2): 177—179 (in Chinese)

4 Gideon Barnea, Meir Markovits, Itamar Navon. Proceeding of Beams 2002. Albuquerque, 2002. 171—174

5 Richardson R A. Proceeding of 1999 Particle Accelerator. New York, 1999. 2149—2151