Real-Time Spot Size Measurement for Pulsed High-Energy Radiographic Machines*

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Abstract

The focal spot size of an x-ray source is a critical parameter which degrades resolution in a flash radiograph. For best results, a small round focal spot is required. Therefore, a fast and accurate measurement of the spot size is highly desirable to facilitate machine tuning. This paper describes two systems developed for Los Alamos National Laboratory's Pulsed High-Energy Radiographic Machine Emitting X-rays (PHERMEX) facility [1]. The first uses a CCD camera combined with high-brightness fluors, while the second utilizes phosphor storage screens. Other techniques typically record only the line spread function on radiographic film, while systems in this paper measure the more general two-dimensional point-spread function and associated modulation transfer function in real time for shot-to-shot comparison.

I. INTRODUCTION

A flash x-ray source is produced when a beam of high-energy electrons impinges on a heavy metal target producing bremsstrahlung radiation. The time-integrated spatial intensity distribution or spot size of this source degrades the resultant image. A radiographic experiment can be well modeled as a linear system in the following way [2]:

$$i(x,y) = o(x,y)*s(x,y)*f(x,y) \tag{1}$$

Where i(x,y) is the resultant image, o(x,y) is the object transmission characteristic, f(x,y) is the film blur characteristic, and s(x,y) is the two-dimensional point-spread function (PSF) of the source, and * denotes convolution. Clearly, as s(x,y) deviates from an ideal delta function, the resolution of the resultant image will be degraded. To evaluate a source for a given radiographic task, it is necessary to characterize the focal spot experimentally. We have adopted a definition proposed by Mueller [3] using the -3 dB point on the modulation transfer function (MTF) curve for reducing the source PSF to a single number spot size for performance comparison across machines.

II. SYSTEM DESIGN

A wealth of literature exists on the various techniques for source characterization [4-7]. The primary methods are illustrated in Table 1. Most of these techniques are applied to low energy machines with small spots and may require multiple pulsing to achieve the desired sensitivity.

Technique	Advantages	Disadvantages
Resolution Pattern	Scanner is not required.	Requires low contrast measurement. Difficult to interpret.
Pin Hole	Yields PSF. Self shielding	Requires multiple shots & large magnification. Hard to manufacture.
Particle Array	Yields PSF	Requires small opaque particles and computer. Poor at high energies.
Knife Edge	Common usage	Assumes isotropic source & yields only LSF. Requires computer.
Streak Camera	One-dimensional time-resolved data.	Assumes isotropic source. Difficult to use. Requires computer.
Large Pin Hole	Yields PSF. Self shielding.	Requires computer. Needs high quality data (i.e. good SNR).

Table 1. Common Spot Size Measurement Techniques

After testing these methods and several others (using type AA radiographic film with 1-mm lead screens), the large pin hole was chosen because it offers several advantages in a real time system. First, the large pin hole is self-shielding, and consequently lowers the scattered background radiation delivered to the CCD camera [8]. Furthermore, it can be used on a single pulse with relatively low magnification. Finally, it indirectly yields a two-dimensional PSF. A block diagram of a prototype system is shown below in Fig. 1.

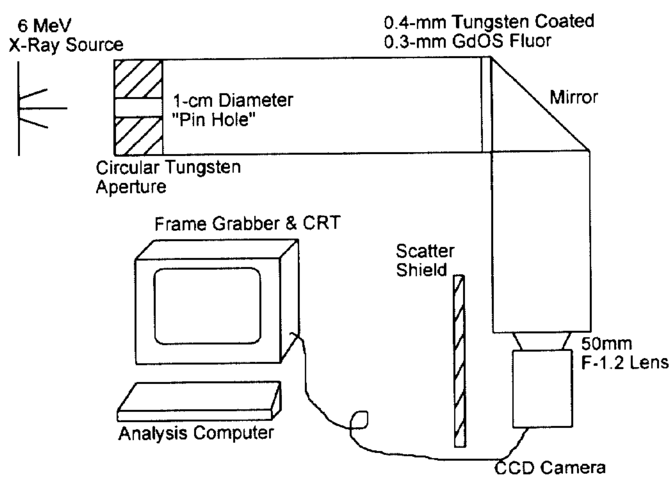

Figure 1. Real-Time Spot Size Camera System

This system images a 10-mm-diameter, 100-mm thick tungsten aperture onto a 0.3-mm thick Gd_2O_2S fluor coated onto a 0.4-mm tungsten intensifying screen. The resulting image is relayed to a VAX 3100 analysis computer by way of

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a front surface mirror, 50mm F1.2 camera lens, and a COHU RS-170 CCD camera with an Analogic DASM 8-bit frame grabber.

The aperture transfer function and the detector blur function are then deconvolved using a Wiener inverse filter [9] to yield the source PSF,

$$S(f) = \frac{I(f)}{O(f)F(f)} \tag{2}$$

Here S(f), I(f), O(f), and F(f) are Fourier transforms of the source PSF, resultant image, the opaque tungsten aperture (a zero-order Bessel function), and the spatial blur function respectively.

The CYLTRAN electron-photon transport code [10] was used to obtain a one-dimensional estimate of the detector blur function at the 6-MeV incident effective photon energy of PHERMEX. The resulting blur function is shown in Fig. 2 below. For our machines, this blur represents a small perturbation on the final result that can be made negligible by using radiographic magnifications greater than two [11].

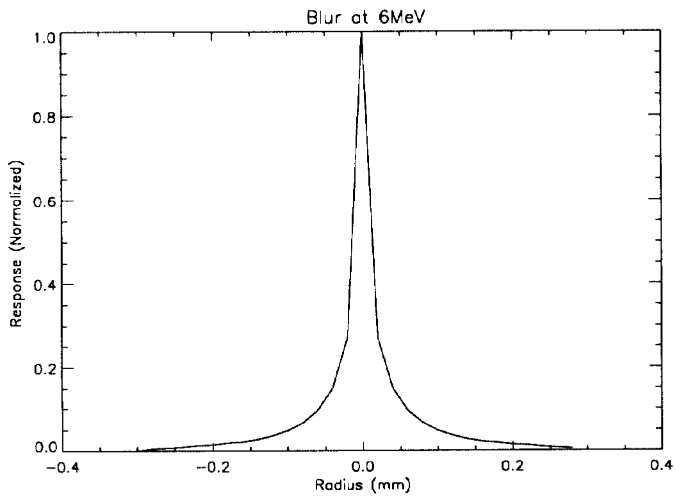

Figure 2. Gd_2O_2S Spatial Blur Function

Several types of commercially available fluors were tested, and the Gd_2O_2S type fluor was superior in all respects. (1) It has a green spectral response that matches the CCD camera spectral sensitivity, (2) has much higher speed than $CaWO_4$, ZnCdS, or LaOBr, (3) has low inherent blur, and (4) is highly resistant to radiation damage [11]. The final screen was specially fabricated by directly coating the Gd_2O_2S onto the tungsten intensifying screen using a lower binder ratio to increase the effective density (from 3.2 g/cc to 4.5 g/cc) and thus increase the speed and lower the inherent blur from secondary electron emission.

Our second approach uses the same basic large pin hole technique with a different imaging system. Rather than using transfer optics and a CCD array, the hole is directly imaged onto a storage phosphor screen, which is then read directly using a 16-bit Molecular Dynamics laser-scanner with an on-board Intel-486 personal computer.

Both systems use in house software (written with the commercially available IDL image analysis package for VAX and IBM PC computers) which was calibrated using synthetic radiographs with known point spread functions.

III. EXPERIMENTAL RESULTS

Figure 3 below shows spline-fit data from a typical machine tune - spot size vs solenoid focus current. Notice the characteristic parabolic shape and the high sensitivity (better than 0.2 mm) of the camera system. The deviation from a parabola at lower focus currents was attributed to pre-collimation of the beam by a tapered beryllium collimator.

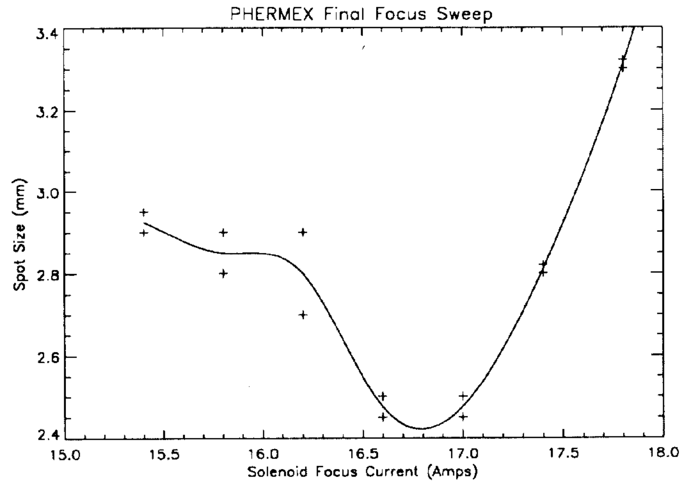

Figure 3. Spot Size vs Final Focus Magnet Current

The reconstructed point spread function (with 2-axis parametric least-squares Gaussian fits) is shown below in Fig. 4, along with the associated (radial-averaged) modulation transfer function in Fig. 5. These results are typical of both systems.

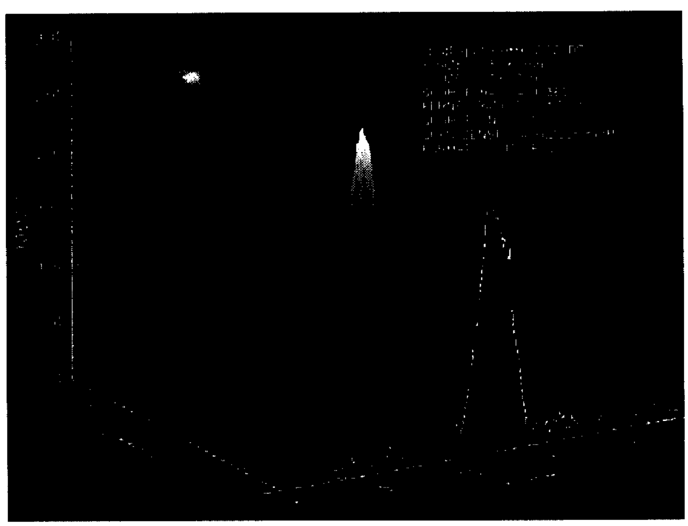

Figure 4. Typical PSF Reconstruction

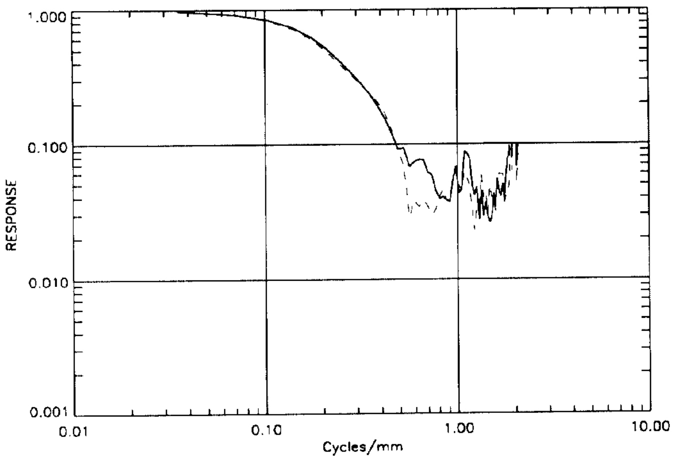

Figure 5. MTF's of Two Identical Pulses Illustrating Machine Repeatability

Based upon our experiments, we estimate the following specifications for each system and for radiographic film [12]:

System-	CCD Camera	Phosphor	AA Film
Acquisition Time	1 min	8 min	2 hr
Sensitivity	0.1 mm	0.1 mm	0.1 mm
Resolution	2-9 mm	0.5-9 mm	0.3-9 mm
Required Dose	10 Rad at Fluor	0.1 Rad	1 Rad
Abs. Accuracy	0.4 mm	0.3mm	0.3 mm
Dynamic Range	8 bits	16 bits	11 bits
SNR (Typical)	13 dB	20 dB	20 dB
Image Size	256x256	512x512	512x512
Detector Cutoff	1.0 Cycle/mm	.2 Cycle/mm	.3 Cycle/mm
Analysis Time	0.5 min	2 min	2 min
Energy Range	0.1 - 30 MeV	0.1 - 50 MeV	0.1 - 50 MeV
Align. Error	0.2 mm	0.1 mm	0.1 mm
Magnification	1.5-2.5	3.0-5.0	2.0-5.0

Table 2. Estimated System Specifications

IV. CONCLUSIONS

Both systems performed well as a machine diagnostic to facilitate tuning. Previously, to obtain and analyze the data for a single shot took several hours. These systems both reduce this turnaround time to a few minutes, dramatically increasing the number and type of parameters that can be easily adjusted. The additional information conveyed by the two-dimensional PSF is also valuable whenever the beam is not isotropic.

The CCD system's primary advantage is the short turn-around time (less than 2 min), which makes it effectively "real-time". The storage phosphor's 16-bit dynamic range yields improved performance at the expense of processing time (typically 5-10 min per event). The quality of the data obtained with storage phosphors is as high as radiographic film. On the basis of our experience using both systems at a variety of radiographic facilities, we recommend the storage phosphor system using a large pin-hole because it offers the best compromise between quality, turnaround time, and ease of use.

V. REFERENCES

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