Radiography and Image Processing

Stephen E. Mitchell, Principal Scientist
National Security Technologies, LLC
mitchese@nv.doe.gov
702-295-3065

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.
Outline

• Introduction
• Pulsed Power
• Diode Physics
• Radiography ABC’s
• Challenges
Introduction

- Subcritical Experiment (SCE) program initiated after 1992 moratorium on underground nuclear testing in support of stockpile stewardship

- High energy radiography was developed over the years to complement existing surface diagnostics (i.e. Photon Doppler Velocimetry [PDV], velocity interferometer system for any reflector [VISAR])

- Material science: Provides spatial view, internal density measurement
"I think you should be more explicit here in step two."

- Marx
- Blumlein
- PFL
Diode Physics

- Hi-Z, TTB, electron $\Rightarrow$ photon converter (e.g. Tungsten or Tantalum)
- Bremsstrahlung photon flux, $\Phi(E)$, goes as $\approx (7.5\times10^{-4}) \times (Z) \times (KE_{\text{electron}})$ in a TTB target

- Diode current may be space charge limited (SCL) in hi impedance configuration

$$ I_{\text{SCL}} \propto \left( \frac{L_{\text{eff}}}{r_a f \left( \ln \left( \frac{r_c}{r_a} \right) \right)} \right)^{3/2} V^{3/2} $$

- Diode current may be magnetically limited (ML) in lo impedance configuration

$$ I_{\text{ML}} \propto \left( \frac{\gamma^2 - 1}{\ln \left( \frac{r_c}{r_a} \right)} \right)^{1/2} $$

where

$$ \gamma = \frac{qV}{mc^2} + 1 $$

Example Radiographic Setup

Dual Radiographic Configuration Produces Two Time-Separated Radiographs of Equivalent Views - Example
Diagnostics on Radiographic System

Diode Assy.

Pinhole cameras

Diode Assy. Cutaway cartoon

Pinhole camera radiograph
Radiography ABC’s

Test setup for spot-size measurement

Test setup for detector blur measurement
Radiography ABC’s (Cont.)

Radiographic Magnification = \( \frac{C1 + C2}{C1} \)

Source Magnification = \( \frac{C2}{C1} \)

System Resolution = \( \frac{**}{\text{Radiographic Magnification}} \)
Radiography ABC’s (Cont.)

Spot-Size (blur) Measurement Algorithms and Metrics

\[ AWE_{ss} = 2.5 \times (X_{0.25} - X_{0.75}) \]

\[ \text{LSF} = \frac{d(\text{ESF})}{dX} \]

\[ \text{MTF} = \text{ABS}(\text{FFT}(\text{LSF})) \]

\[ \text{LANL}_{ss} = \frac{1}{(1.4 \times Fc)} \]

\[ \text{PSF} = \text{ABL}^{-1}(\text{LSF}) \]

\[ \text{LLNL}_{ss} = \text{FWHM}(\text{PSF}(r)) \]

\[ \text{SNL}_{ss} = \text{RMS}(\text{PSF}(r)) \]
De-Blurring (De-convolution)

Observed “blurred” Image

De-convolved with proper PSF…

De-blurred Image
Raw and De-blurred Scatter Test Object

18 mm dia. Ta Shims
Thickness (mm)

- 0.89
- 0.71
- 0.51
- 0.30
- 0.10
- 3.00

Line slice through scatter test object

Line slice through de-blurred scatter test object

Nevada National Security Site
Managed and Operated by National Security Technologies, LLC
Transfer Response Relation to Areal Density

Radiograph of a graded collimator

Logarithmic ratio of Radiograph of a graded collimator to flat-field

Scaled (calibrated) to yield 2-D areal density plot
Transfer Response & Selective Image De-coupling (Ideal)

\[ D = D_0 e^{-\mu_1 x_1} \]

\[ \frac{D}{D_0} = e^{-\mu_1 x_1} = T_1 \Rightarrow \ln \left( \frac{D}{D_0} \right) \propto \mu \]

\[ D = D_0 \left( e^{-\mu_1 x_1} \right) \left( e^{-\mu_2 x_2} \right) \]

\[ \frac{D}{D_0} = \left( e^{-\mu_1 x_1} \right) \left( e^{-\mu_2 x_2} \right) = T_1 T_2 = \prod_{n} T_n \]
Scattered Field (real world)

\[ D \propto D_0 e^{-\mu_1 x_1} + S_1 \]

\[ D \propto D_0 \left( e^{-\mu_1 x_1} \right) \left( e^{-\mu_2 x_2} \right) + S_2 \left( e^{-\mu_1 x_1} \right) + S_1 \left( e^{-\mu_2 x_2} \right) \]
Complications and challenges

• Bremsstrahlung source spectrum (non mono-energetic source spectrum)

• Scatter field contribution

• DOF issues; ill-defined light origin within scintillator, “fast” low F-number imaging system, light collection efficiency

• Non-symmetric objects – beyond Abel transforms toward Radon transforms with >2 line of sight views

• Normalization – flat field and dark field normalization, shot-shot variations