PERFORMANCE EVALUATION OF MOLYBDENUM BLADES IN AN X-RAY PINHOLE CAMERA

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ABSTRACT

At Diamond Light Source transverse profile measurements of the 3 GeV electron beam are provided by x-ray pinhole cameras. From these beam size measurements and given knowledge of the lattice parameters the emittance, coupling and energy spread are calculated. Traditionally, tungsten blades are used to form the pinhole aperture due to the opacity of tungsten to x-rays in the keV spectral range. The physical properties of tungsten also make it difficult to work. To achieve the 25 µm x 25 µm aperture size required for high resolution measurements it is necessary to mount these tungsten blades in an assembly whereby the pinhole aperture size is defined by precisely machined shims. Here we propose to replace the tungsten blade and shim arrangement with machined molybdenum blades and evaluate the performance of the resulting imaging system.

X-RAY PINHOLE CAMERA SETUP

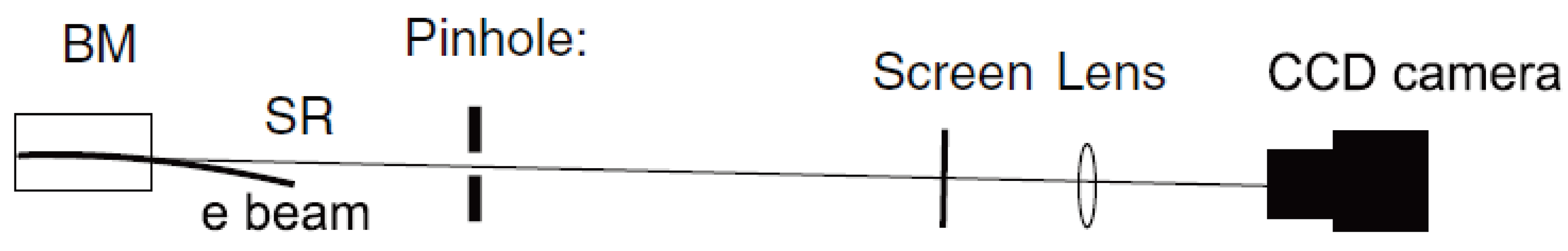

Figure 1: Schematic of the pinhole camera system for synchrotron radiation in the 15 – 60 keV spectral range [1]. The scintillator screen is Prelude 420.

PINHOLE SYSTEM	DESCRIPTION	PINHOLE ASSEMBLY
1	Used in the vertical emittance feedback system [2].	Two orthogonal stacks of 25 mm(h) x 1 mm(v) x 5 mm(d) tungsten blades separated by precisely machined shims.
2		
3	Used for research and development	Combination of tungsten blades with shims and machined molybdenum blades (see Figure 2).

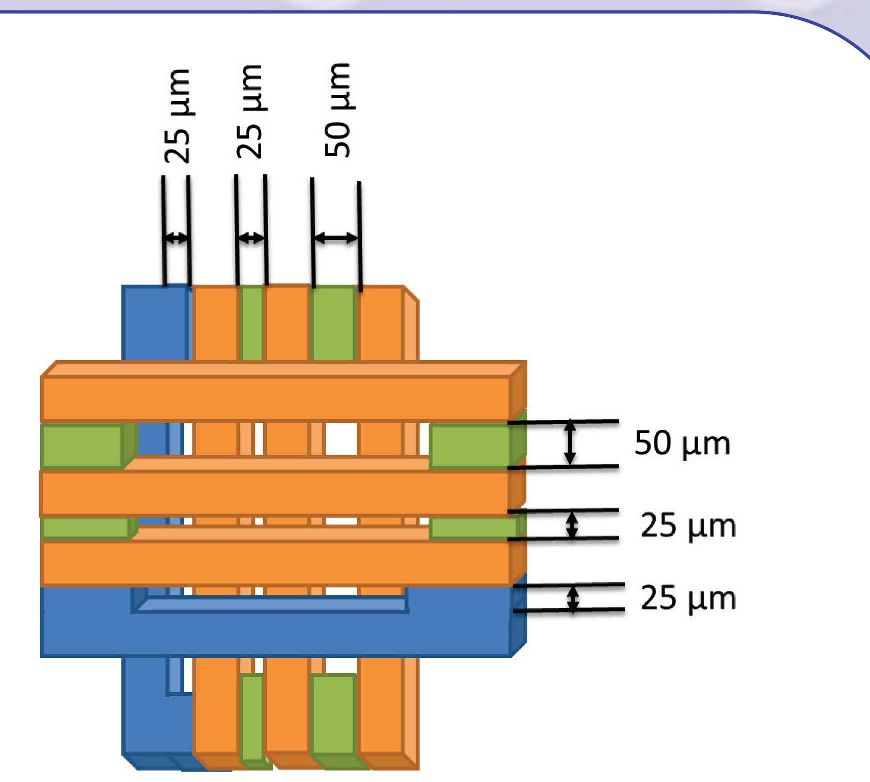

Figure 2: A schematic of the downstream view of the pinhole 3 assembly showing the arrangement of the machined molybdenum blades (blue), tungsten blades (orange) and shims (green).

COMPARISON OF PINHOLE ANGLE SCANS

Horizontal and vertical angle scans were performed for the 25 µm x 25 µm molybdenum and tungsten apertures of pinhole system 3.

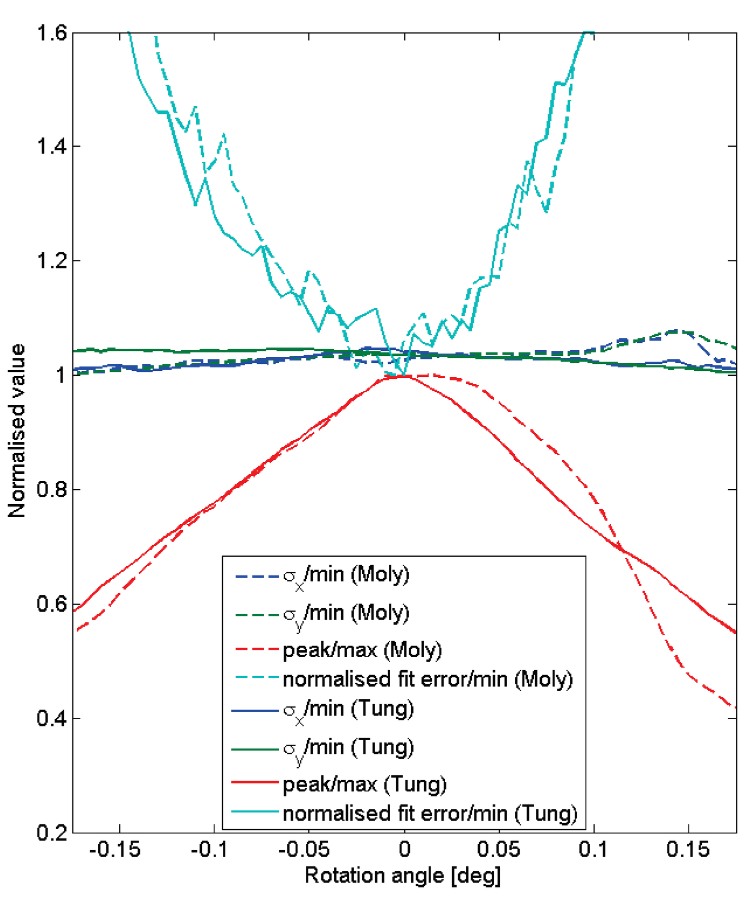

Figure 3: Horizontal rotation scans on pinhole camera 3 of the molybdenum aperture (dashed lines) and tungsten aperture (sold lines).

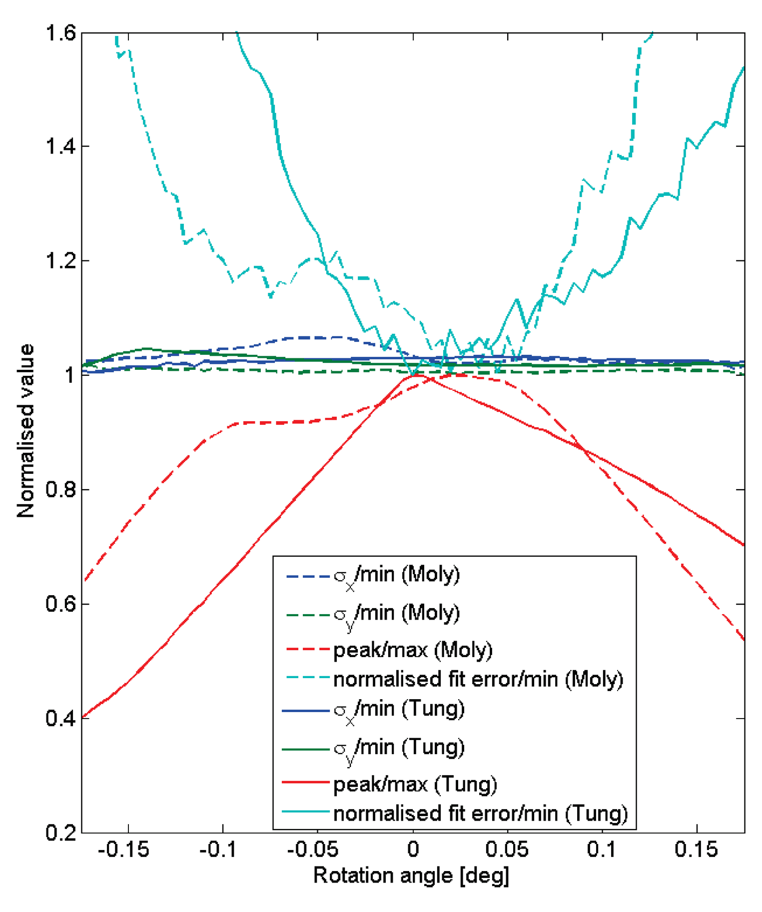

Figure 4: Vertical rotation scans on pinhole camera 3 of the molybdenum aperture (dashed lines) and tungsten aperture (sold lines).

- Peak intensity of tungsten aperture shows the expected behaviour whereas the molybdenum aperture exhibits a non-linear distribution with strong asymmetry. The observed asymmetry may be explained by the molybdenum blade on one side and a tungsten blade on the other.
- The nonlinear dependence of the measured peak intensity must be related to the transmission of x-rays in molybdenum and could indicate oxide or nitride growth on the molybdenum blades.
- The measured transverse beam sizes and fit errors as a function of rotation angle in the horizontal and vertical directions are not seen to strongly differ between the molybdenum and tungsten apertures.

CONCLUSION

Angle scans of the pinhole assembly relative to the incident synchrotron radiation beam have been performed to study the opacity of molybdenum to keV x-rays. Results show that although the peak intensity as a function of angle for the molybdenum aperture is somewhat non-linear in comparison to tungsten, this has a negligible affect on the beam size measurement.

PSF measurements of each pinhole imaging system were acquired using the Touschek lifetime with a good level of repeatability. By replacing the tungsten and shim assembly with machined molybdenum blades, the numerous of degrees of freedom which affect the aperture size in the pinhole system were removed such that the PSF was reduced.

PSF MEASUREMENTS USING THE TOUSCHEK LIFETIME

Touschek Lifetime

Ultra-relativistic, plane orbit approximation [3, 4]:

$$\frac{1}{T_\ell} \approx \left\langle \frac{c r_p{}^2 N_p}{2\sqrt{\pi}\gamma^2 \sigma_s \sigma_x \sigma_y \delta_m^2} \right\rangle \qquad (1)$$

T_ℓ = Touschek lifetime
c = Speed of light
r_p = Classical particle radius
N_p = Number of particles in bunch
γ = Lorentz factor
σ_s = Bunch length
σ_x = Horizontal beam size
σ_y = Vertical beam size
δ_m = Momentum spread

Touschek dominated beam:
400 bunch, 200 mA such that $\tau \approx T_\ell$

In the Touschek dominated regime the measured beam lifetime τ is used as a proxy measurement for the true beam size σ_y as:

$$\sigma_y = k\tau \qquad (2)$$

where k is a scaling factor.

Vertical Beam Size Measurement

Acquired image is processed by 2D Gaussian fitter.

Subtraction in quadrature given a Gaussian beam profile and point spread function (PSF):

$$\sigma_M = \sqrt{\sigma_y^2 + \sigma_{PSF}^2} \qquad (3)$$

Substituting Eq. (2) into (3):

$$\sigma_M = \sqrt{(k\tau)^2 + \sigma_{PSF}^2} \qquad (4)$$

σ_M = Measured beam size from Gaussian fit of image
σ_y = True vertical beam size
σ_{PSF} = Point spread function

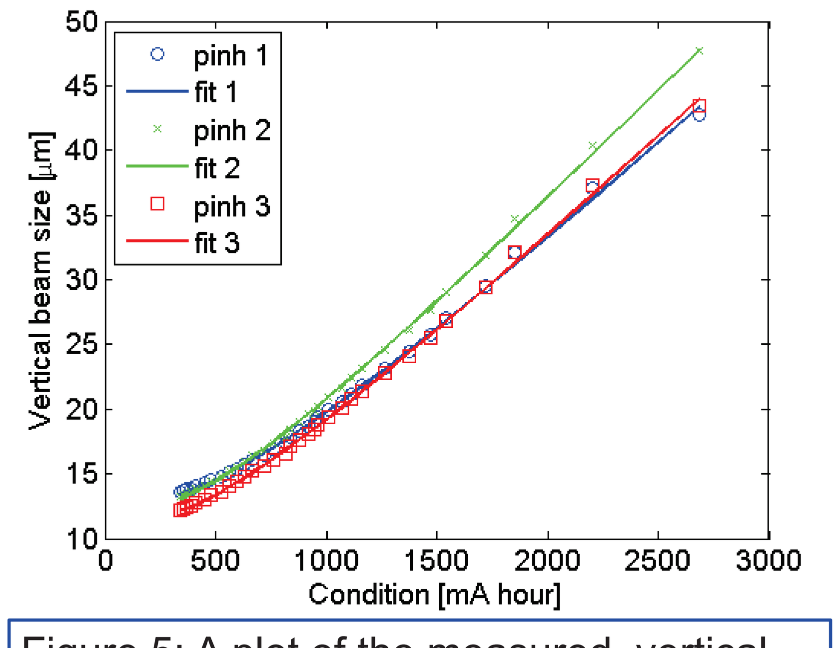

Figure 5: A plot of the measured vertical beam size against beam condition for pinhole systems 1, 2 (measurement 1) and the molybdenum aperture of pinhole system 3.

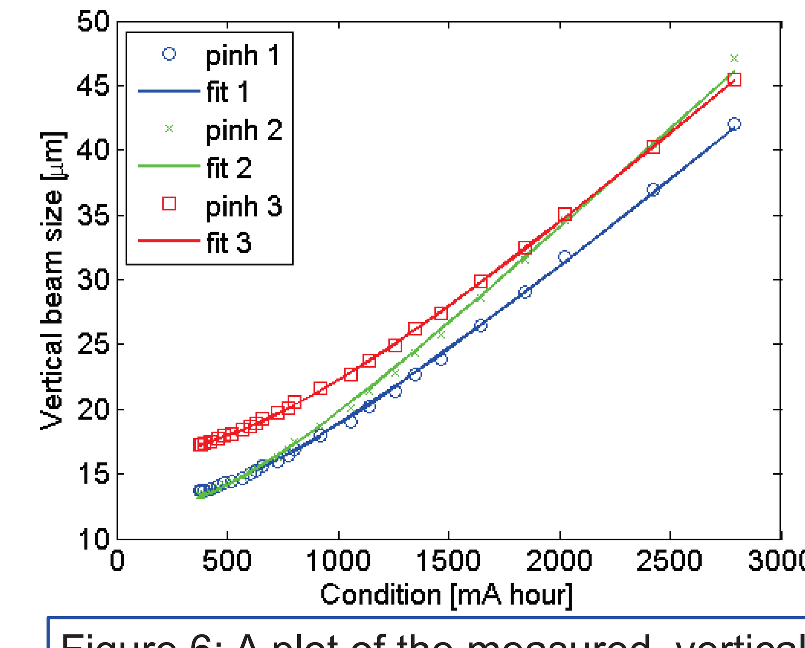

Figure 6: A plot of the measured vertical beam size against beam condition for pinhole systems 1, 2 (measurement 2) and the tungsten aperture of pinhole system 3.

Table 1: Fit results of the scaling factor and PSF from Figures 5 and 6 using Eq. (4).

Pinhole camera	Measurement 1		Measurement 2	
	k [μm mA^{-1} h^{-1}]	σ_{PSF} [μm]	k [μm mA^{-1} h^{-1}]	σ_{PSF} [μm]
1	0.0155	12.36	0.0143	12.33
2	0.0173	11.67	0.0160	11.70
	Molybdenum		Tungsten	
3	k [μm mA^{-1} h^{-1}]	σ_{PSF} [μm]	k [μm mA^{-1} h^{-1}]	σ_{PSF} [μm]
	0.0159	10.82	0.0152	16.28

REFERENCES

[1] C. Thomas et al., "X-ray pinhole camera resolution and emittance measurement", Phys. Rev. ST Accel. Beams 13, 022805, (2010).
[2] I.P.S. Martin et al., "Operating the Diamond Storage Ring with Reduced Vertical Emittance", Proc. of IPAC2013, Shanghai, China, MOPEA071.
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