PERFORMANCE OF A REFLECTIVE MICROSCOPE OBJECTIVE IN AN X-RAY PINHOLE CAMERA

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ABSTRACT

X-ray pinhole cameras are used to measure the transverse beam profile of the electron beam in the storage ring from which the emittance is calculated. As improvements to the accelerator lattice reduce the beam emittance, e.g. with upgrades to fourth generation synchrotron light sources, likewise the beam size will be reduced such that micron and sub-micron scale resolution is required for beam size measurement. Therefore the spatial resolution of the pinhole camera imaging system must be improved accordingly. Here, the performance of a reflective microscope objective is compared to the high quality refractive lens which is currently in use to image the scintillator screen to the camera. The modulation transfer functions for each system have been assessed and will be discussed.

MODULATION TRANSFER FUNCTION (MTF)

The MTF (or spatial frequency response) is the magnitude response of the optical system to sinusoids of different spatial frequencies [1]

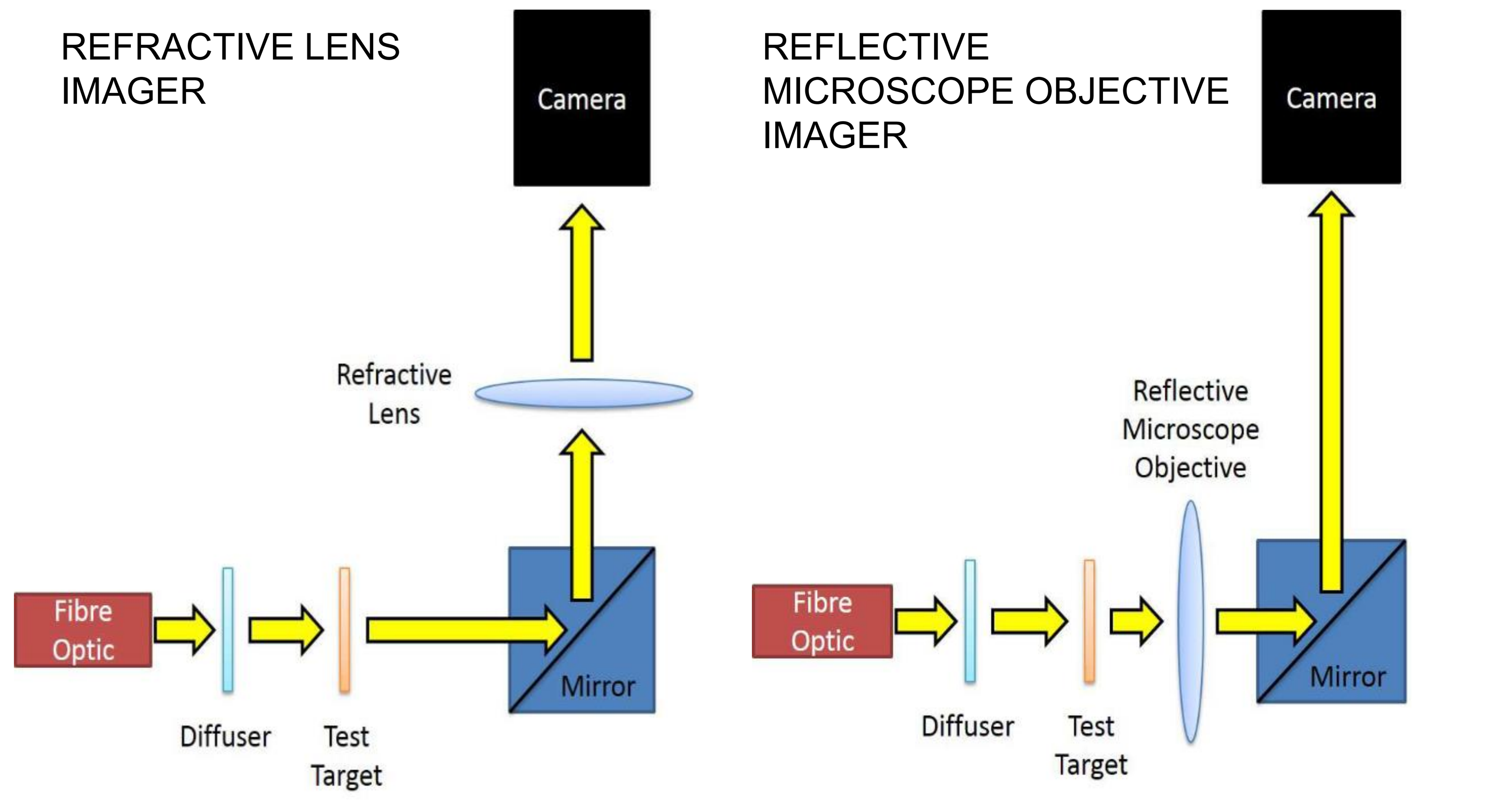

Figure 1: Schematics of the Schneider-Kreuznach Componon-S 2.8/50 refractive lens imager (left) [2] and Newport 50105-01 reflective microscope imager (right) [3] as tested in the lab..

	REFRACTIVE LENS	REFLECTIVE MICROSCOPE OBJECTIVE
F-number	2.8 to 8	1.25*
Numerical Aperture	0.18 to 0.06*	0.4
Focal length	50.2 mm	160 mm (back) 13 mm (effective)
Working distance	-	24 mm
Magnification	1	15
Transmission	400-700 nm	200-1000 nm

*denotes calculated values

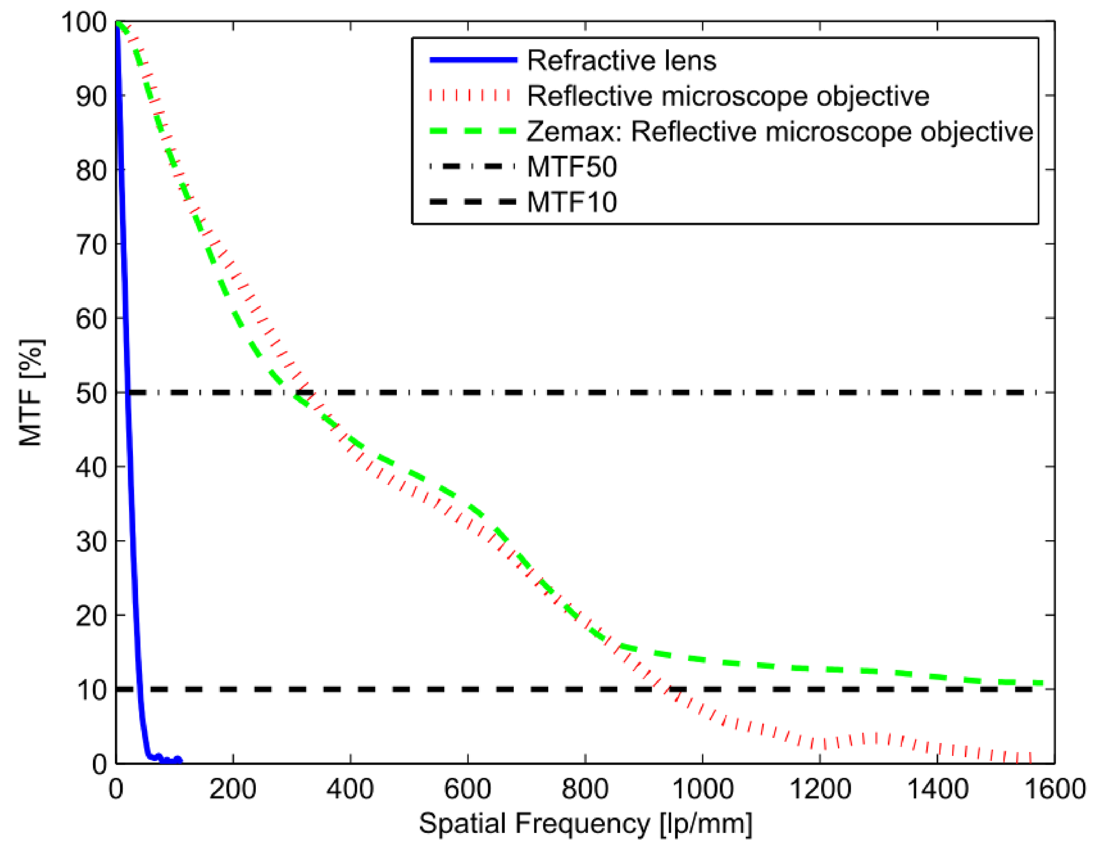

Figure 3: Comparison of the measured MTF of the refractive lens and the reflective microscope objective. Also plotted is the expected MTF from Zemax for a similar microscope objective from Thorlabs.

	REFRACTIVE LENS	REFLECTIVE MICROSCOPE OBJECTIVE
MTF10	42 lp/mm	936 lp/mm

X-RAY PINHOLE CAMERAS

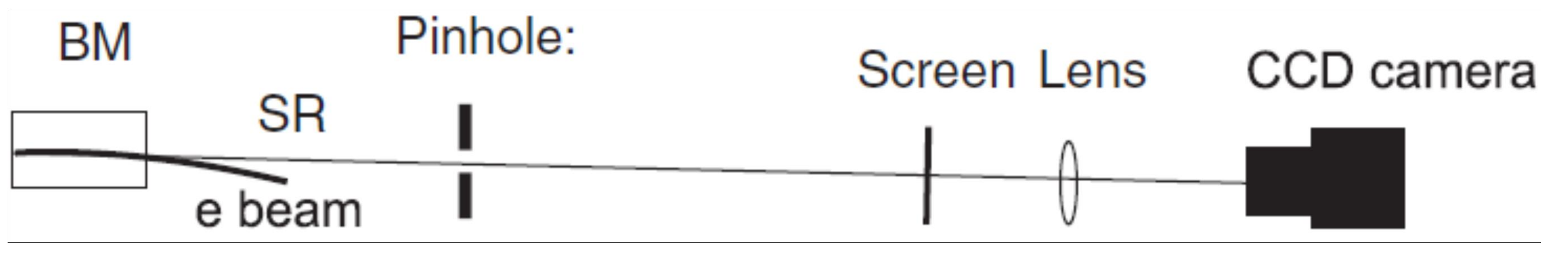

Figure 2: Schematic of the pinhole camera system [4]. A folding mirror is also typically included downstream of the scintillator such that the refractive lens and camera may be located away from the X-ray beam.

PINHOLE CAMERA	DESCRIPTION
1	Used in the vertical emittance feedback system [5].
2	
3	Used for research and development.

POINT SPREAD FUNCTION (PSF) MEASUREMENTS

In the Touschek dominated regime (400 bunch, 200 mA) the measured beam lifetime (or condition) τ is used as a proxy measurement for the true beam size σ_y as:

$$\sigma_y = k\tau \qquad (1)$$

where k is a scaling factor [6].

Subtraction in quadrature given a Gaussian beam profile and PSF σ_{PSF} gives the measured beam size σ_M as:

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

Substituting Eq. (1) into (2):

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

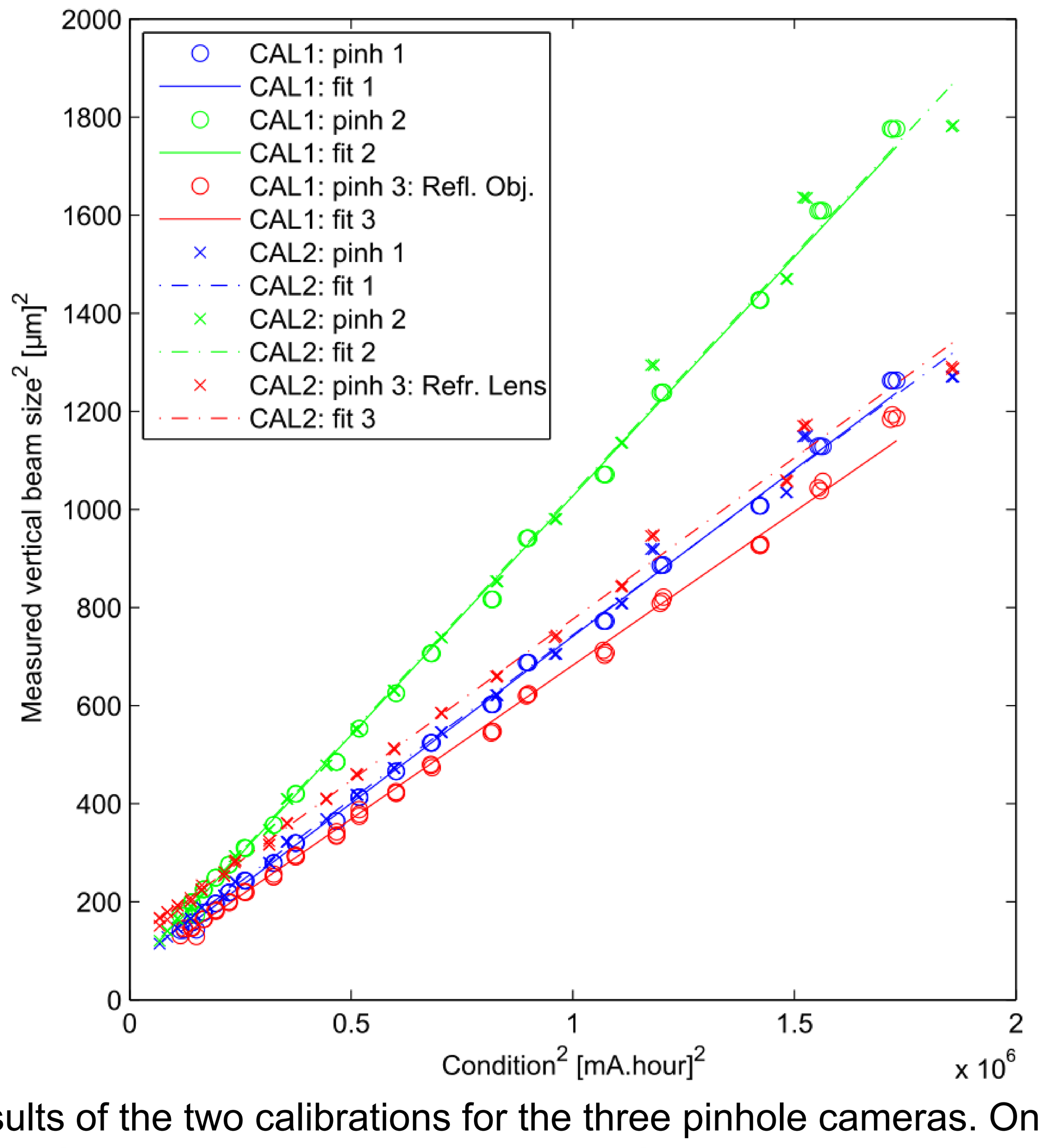

Figure 4: Results of the two calibrations for the three pinhole cameras. On pinhole camera 3, the reflective microscope imager and refractive lens imager were in operation for calibrations 1 and 2 respectively.

Comparisons between the pinhole cameras should not be made. This is due to the differences in the optical elements of each pinhole camera, such that the PSF contributions are unique to each system. Thus comparisons should only be made between the two calibrations of each pinhole camera.

PINHOLE CAMERA	CAL 1		CAL 2	
	k [µm mA^{-1} h^{-1}]	σ_{PSF} [µm]	k [µm mA^{-1} h^{-1}]	σ_{PSF} [µm]
1	0.026	7.8	0.026	8.6
2	0.031	7.2	0.031	7.5
	Reflective microscope imager		Refractive lens imager	
3	0.025	**7.4**	0.026	**10.9**

30% improvement

CONCLUSION

The spatial resolution of pinhole cameras must be improved for operation in future light sources. Although the fundamental limitation arises from the pinhole aperture itself, another important contribution to the overall point spread function comes from the scintillator screen. Depending upon budget and given a large source-to-screen magnification, direct imaging of the X-ray beam would inherently remove this point spread function contribution however, such detectors are significantly more expensive and tend to have a large pixel size. Instead, the results presented in this paper show that a thin scintillator screen coupled with a reflective microscope objective which has a large numerical aperture can provide a significant reduction to the overall PSF of the pinhole camera whilst maintaining the frame rates needed for online feedback.

REFERENCES

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