Investigating Schlieren Microscopy as a Method of Optic Inspection

Contact *samuel.buck@stfc.ac.uk*

S. Buck, R. Clarke, D. Carroll, R. Heathcote
Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell, Didcot, Oxfordshire, OX11 0QX

Introduction

The current method of optic inspection along the Vulcan beamline requires physical inspection and close human interaction with the use of a white light source. This poses a problem when it comes to inspection of the optics inside the compressor chamber as these are kept under vacuum, inspection ports are usually not suitably placed for this particular task. The aim of this investigation is to design and evaluate a method of remote inspection wherein image planes are mapped and assessed to determine optical damage in a beam line

Theory

An afocal system (shown in figure 1) is a combination of two lenses such that the distance between them is equal to the sum of the focal lengths.

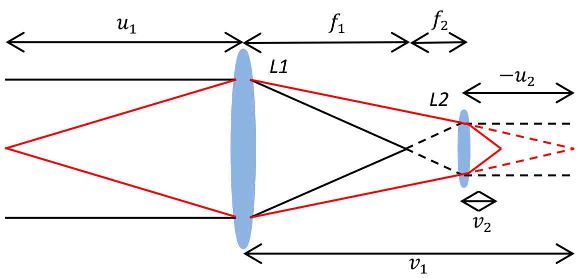

Figure 1: Schematic of an afocal system – to define terms.

For $f_1 \neq f_2$ this has a magnification property. There is a focal point between the two lenses; physically blocking this permits only non-collimated light (i.e. light scattered from optic imperfections) to proceed, and be imaged by the second lens.

By applying the thin lens formula, a mapping between u_1 & v_2 can be created (see table 1) where u and v are the distances from the lens to the object and lens to image respectively, the subscript denotes which lens they correspond to. Note the specific conditions for u_1 for which an image at v_2 is behind the second lens, which is dependent on the properties of the lenses involved.

u_1	v_1	u_2	v_2
$0 < u_1 < f_1$	$0 > v_1 > -\infty$	-	-
$f_1 < u_1 \leq \frac{f_1}{f_2}(f_1 + f_2)$	$\infty > v_1 \geq f_1 + f_2$	$-\infty < u_2 \leq 0$	$f_2 > v_2 \geq 0$
$\frac{f_1}{f_2}(f_1 + f_2) < u_1 < \infty$	$f_1 + f_2 > v_1 > f_1$	$0 < u_2 < f_2$	$0 > v_2 > -\infty$

Table 1: A mapping of object and image distances of an afocal system.

Method

A mock beam path was created, shown in figure 2, with a selection of poor quality sample mirrors. The aim was to distinguish the camera positions required to focus on the image planes in order to capture the quality of the collimation (and hence the quality of the involved optic).

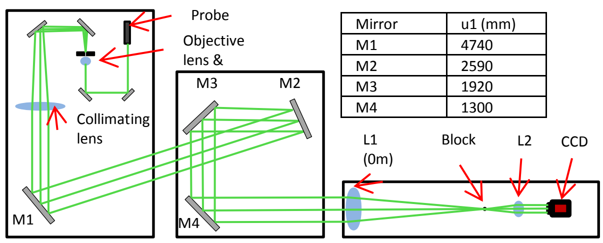

Figure 2: Beam path through optical test setup.

From the theory, by scanning a camera up to a distance of f_2 from *L2*, we should be able to locate any desired image plane up to a distance of $\frac{f_1}{f_2}(f_1 + f_2)$ in front of *L1*, past f_1.

As the mirrors/gratings are not normal to the beam, the image plane for each surface will be tilted differently for each optic, depending on the incidence angle and distance from the imaging system. This tilt can be taken into account by rotating the CCD with respect to the image planes; however, this will not be further investigated during the tests.

One problem which could arise is the 'crossover', or merging of images; i.e. a scratch on one mirror being still apparent on the image plane of the next.

Results & Analysis

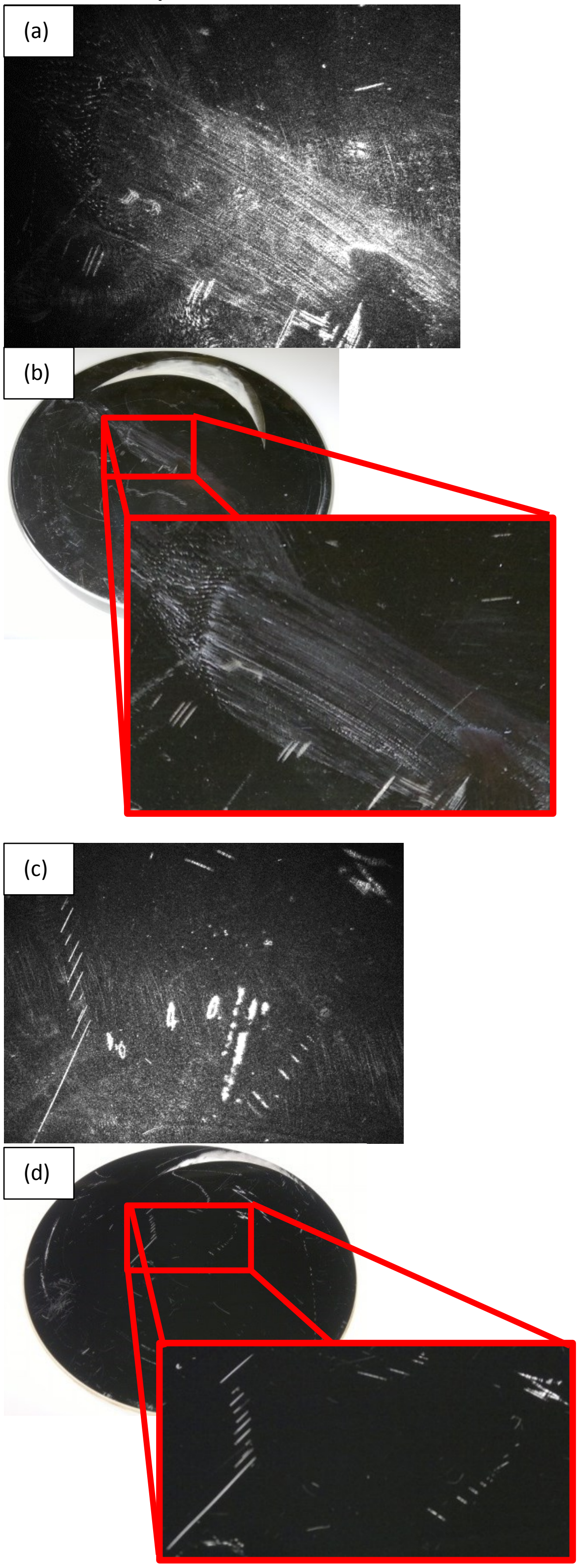

Figure 3: Images of optic surfaces. (a) M2 dark field, (b) M2 photograph, (c) M4 dark-field image, (d) M4 photograph. Dark field images were taken via the method described previously, photographs were taken with an SLR camera.

Image planes were immediately identified using the setup shown above. Images obtained for mirrors M2 & M4 are shown – and compared to photos of the mirrors – in figure 3.

The dark field (Schlieren) images taken clearly show the damage on the mirror surfaces. As predicted however, the sharpness varies along the horizontal axis of each image, particularly evident in figure 3(c).

Furthermore, the reference photos of the mirror surfaces, shown in 3(b) and 3(d), indicate that only a small portion of the optic was sampled. Additional information would be available if the CCD chip size was increased or the CCD was able to translate sideways to scan the mirror surface. Image plane merging was not a problem in the trial as the mirror spacing was sufficiently large. Nevertheless, to counter this risk would require a larger f_2 – increasing the domain of image locations to allow a greater precision.

Conclusions

Schlieren microscopy can very easily be used as a remote inspection tool, the potential of which could be to assess quality of optics along an inaccessible beam path. Images can be taken up to distances dependent on the lenses used; however these have an effect on the scale and camera position precision of obtainable images. More research and testing are required before this system can be employed on the Vulcan compressors.

Future Work

The model could be improved to allow the CCD to rotate about its chip to examine (and apply) the relationship between the object's angle of incidence to the required chip rotation. This was briefly tested to find better focusing; however the varying magnification caused aberrations, this needs investigating further.

Further work would be necessary to allow a greater range of sample distances; objects that are further than $\frac{f_1}{f_2}(f_1 + f_2)$. This could be achieved through the addition of a 1-1 imaging lens to map images formed between the blocked focal spot and $L2$.
Also, more specifically, the Vulcan diagnostic tables already involve multiple afocal systems for other purposes – these would have to be taken into account when calculating image plane locations.