Development of a compact tool for sealing the compensator group in final stages of alignment

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ABSTRACT

A high-precision, low-cost tool for optimal alignment of a compensator group in anamorphic objectives is presented. The system provides highly accurate information by analyzing the axis and field PSFs in the focal plane of the optical system under test. The PSFs are provided by a bundle of 9 different pigtailed laser diodes placed in the object field, and they are recorded by a lensless 2/3" CCD camera. The comparison of the simulated and obtained PSFs allows determining the optical element introducing the differences so action may be taken precisely on that element. The system is especially useful in non-rotationally symmetrical systems, where errors in axis position result into asymmetries of the PSF images. The tool is used for precise alignment of the cylindrical lenses in the compensator group of an anamorphic objective prior to sealing. Results show the system is able to detect misalignments of 100µm and axis positioning errors of just 30arcsec using off-the-shelp components without the need of high-precision positioning equipment.

Keywords: alignment, PSF, optomechanics, optical testing, image quality, anamorphic system

1. INTRODUCTION

As every optical designer knows, after carefully selecting curve combinations, thicknesses, and analyzing the tolerances which might be required for optimal performance of the system, the final moment when the system needs be constructed and evaluated is still giving a further complication from ideal software design to real-world positioning. The mechanical tolerances of rings and positioners, the type of mount used, the tilt of the lens components, and the orientation of each of them in case of a non-rotationally symmetrical system, are variables which need to be accurately fixed in the final stages of alignment, prior to sealing lens groups [1] .

Anamorphic objectives are one example of the high-precision, non-rotationally symmetrical optical systems which are currently being designed and built. Although well-designed mechanical mounts normally do most of the work regarding positioning and centering, they normally are quite ineffective regarding the orientation of axis in astigmatic or cylindrical elements.

A number of metrological techniques are available to qualify and quantify the performance an optical system [2]. Both interferometric and non-interferometric techniques, such as lateral-shearing interferometers or Shack-Hartmann sensors, are commonly used to test the performance of an optical system. These techniques, however, measure the wavefront leaving the optical system under test at its exit pupil. This procedure normally prevents them from given information on which is the element which is responsible of the main part of the image quality loss.

A classical technique developed by H. H. Hopkins and H. J. Tiziani [3] is able to test the proper alignment of the system while providing the essential information on the misaligned elements, analyzing the information contained in the image plane. It detects and quantifies these misalignments using the reflection of an image on the surface of the elements to do the measurement. Several commercial alignment systems have been based on this technique [4,5]. However, they usually need a high precision rotary system and thermal stabilization to assure the reference.

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A complementary tool for compensating both inaccuracies in positioning, tilting and axis orientation will be presented based in obtaining the PSFs of an array of nine pigtailed laser diodes at different field positions. The PSFs are then acquired by a lensless CCD camera with small pixel size. The analysis of the position, size and symmetry of the obtained images will provide the information on the mounting errors introduced. The technique is made of off-the-shelf optical components and fully self-referenced, so no thermal stabilization is required.

2. WORKING PRINCIPLE

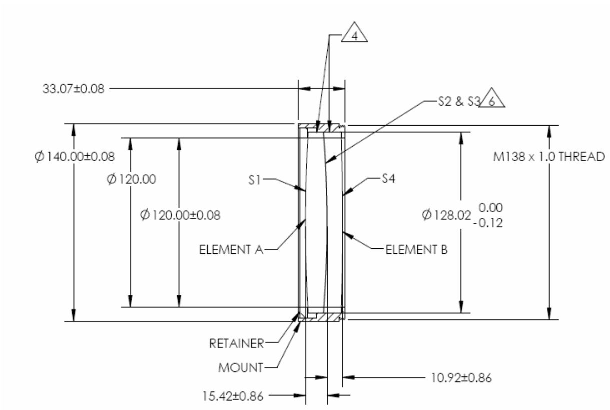
The proposed working principle is both simple and intuitive. Rather than pupil analysis techniques, usual in optical metrology equipment, we turned into focal plane analysis as far as our interest was centered in image quality assessment. As far as we were interested in full-field information, an object consisting of a 3x3 array of pigtailed laser diodes was used. Distances were fixed so as to cover the maximum area in the entrance pupil of the optical system under test.

The array of laser diodes provides a set of divergent fans which are collimated using an achromatic doublet. These collimated fans pass through the system under test and are collected by another achromatic doublet, which forms nine independent PSFs onto a CCD sensor (Fig.1). Although obviously there is an effect onto the PSFs of both the collimator and the objective, they are off-the-shelf lenses with well-known thicknesses, materials, curvatures and tolerances (see fig.2 for the collimator, as an instance) allowing a precise simulation of expected behavior using conventional optical design software.

Fig. 2-1. Conceptual design. An array of pigtailed laser diodes is collimated though the system under test, and a known objective focuses them on the CCD array. All optical components are commercial.

Thus, nine different PSF images at different field positions are obtained on the sensor, and nine additional ones are computed from optical system design software. Each misalignment of an element has a given effect on the PSFs, either on its shape or on its position. This means that, once the set of nine PSFs is acquired, an analysis of the results allows to detect which is the element introducing the main image error and its correction. Both the definition of a merit function covering deviations of all PSFs and allowing experimental alignment optimization, or the simulation of the alignment problems introducing misalignments in the simulated system which reproduce the real patterns obtained are alternatives as working procedure.

Fig.3 shows, as an example, the analysis of results for the case of a two-lens system constructed using a pair of achromatic doublets with N=4 and EFL 100mm, for a decentering of the first doublet of 0.5mm. Fig.3a shows the displacement of the spots for the central cross of laser spots, which would allow detecting the displacement misalignment being considered, and the change in shape of the PSF along the horizontal axis (fig.4b) and the comparison of PSFs given the position relative to the central axis of symmetry is normalized. The combination of changes in position of spots from expected, and the type of deformation appearing in the PSFs allows developing alignment procedures for the considered optical system (Fig.4) easily applicable in the workshop.



	ELEMENT A		ELEMENT B			
	S1	S2	S3	S4		
SHAPE	CONVEX	CONVEX	CONCAVE	CONVEX	EFL (AT 587.6nm)	1,900.24
RADIUS	1,131.72	-780.87	-779.37	-2,704.01		
SURFACE QUALITY	60-40	60-40	60-40	60-40	BFL (AT 587.6nm)	1,887.58
CLEAR APERTURE	124.50	124.50	124.50	124.50		
BEVEL MAX FACE	0.4mm x 45°	0.4mm x 45°	0.4mm x 45°	0.4mm x 45°	ALL DIMS IN	mm

Fig. 2-2 Specifications of a commercial lens used as a collimator. Full information is provided allowing precise simulation of expected image quality.

The system in addition, is especially sensitive regarding the axis orientation of non-rotationally symmetrical systems, such as the anamorphic lens being considered as an object. In these cases, the presence of a cylinder axis allows to detect very precisely misalignments of the axis of the optical system. For the sake of visualization (fig.2.5), a processed image with PSFs enlarged will be presented. Fig.2-5 shows the perfectly aligned PSF map and the PSF map when a misalignment of 0.1º is introduce din the axis of the cylindrical lens. Analyzing the difference of PSFs it can be shown how axis misalignments of just 0.01º are detectable using this procedure.

(a) (b)

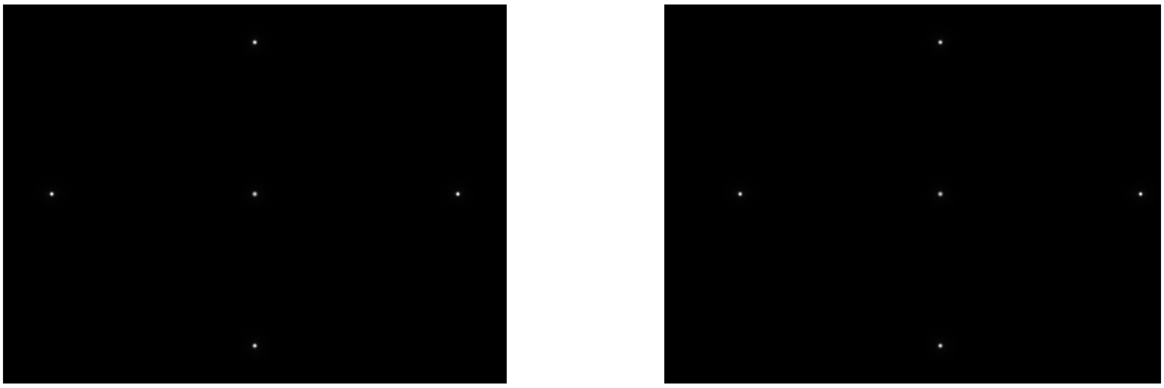


Fig.2-3: Two lens system formed by two achromats. (a) Expected field image at focal plane and b) Simulated spot diagram for a misalignment of 0.1mm in the position of first achromat.

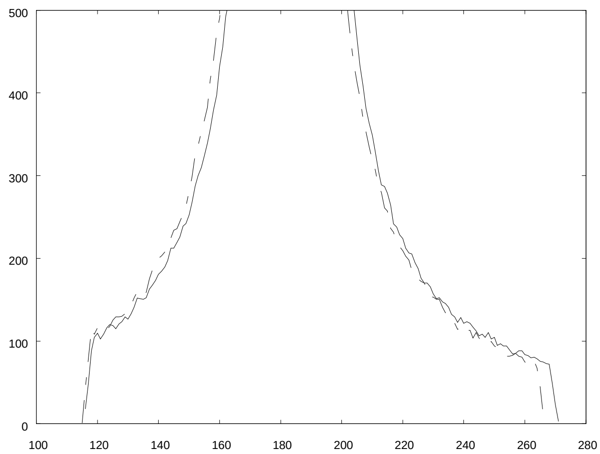


Fig.2-4: Two lens system formed by two achromats. Comparison of field PSFs in horizontal allows to detect the type and estimate amount of misalignment, allowing o develop an alignment procedure for the system under test.

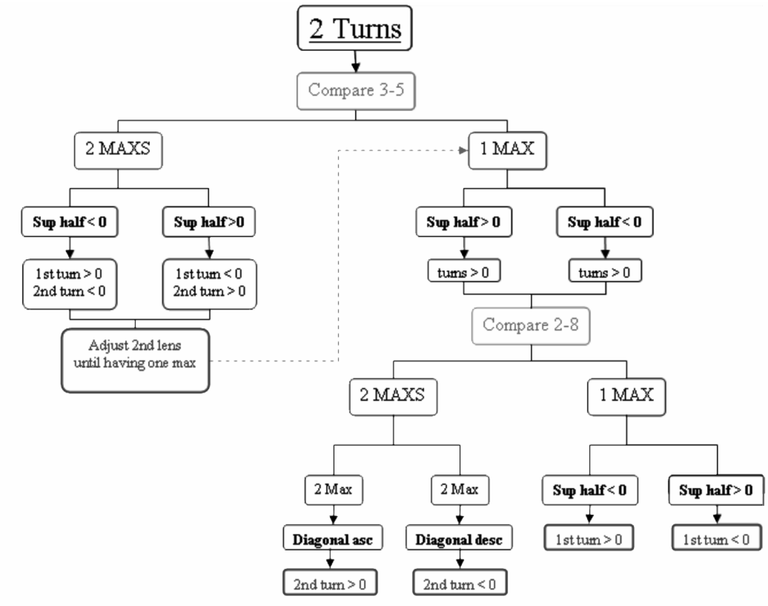
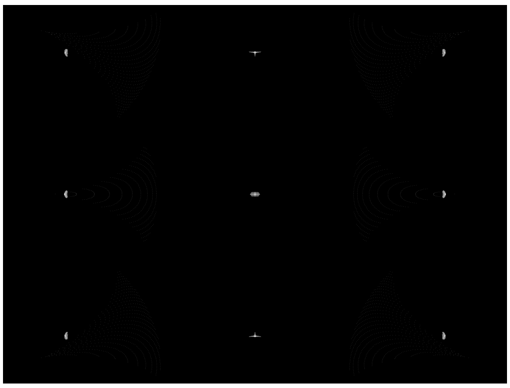


Fig. 2-5.Alignment procedure for a two-lens system.

(a) (b)



[redacted]

(c) (d)

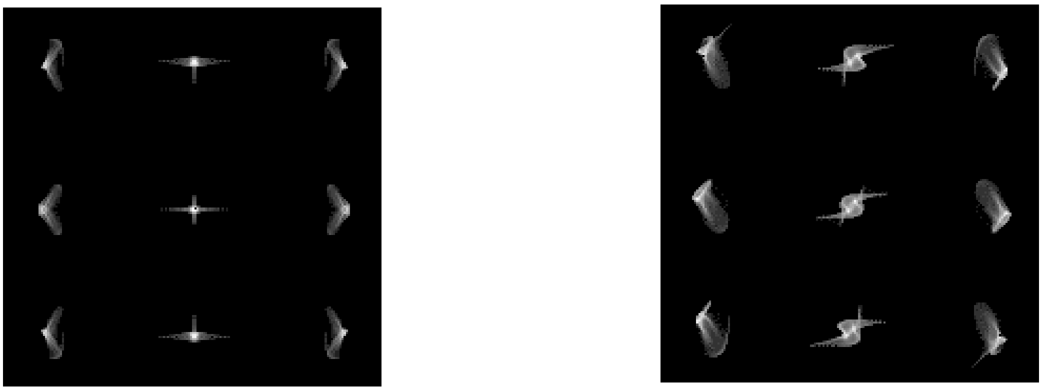


Fig.2-5. a) PSF map of an anastigmatic optical system. b) Procedure for enlarged PSf representation ; c) Perfectly aligned anastigmat; d) Axis of cylindrical lens tilted by 0.5º

3. CONSTRUCTION OF THE SYSTEM

3.1 Elements of the system

In the case we are presenting, the optical system under test was an anamorphic objective which had a field of view of up to 110mm, with a focal length of 70mm, designed for a 2/3" sensor. This pushed to use a collimator with diameter larger than 110.0mm, which was found to be an achromatic doublet of aperture 128.02mm. Due to the large EFL of the collimator, the system was folded using a quarter-wavelength roughness silicon crystal mirror with Al coating. The mirror is placed at 75º relative to the local optical axis of the system, so the system becomes folded at an angle of 32.5º optimum to reduce the size of all the experimental set-up.

The source was constructed using nine 635nm, 2mW laser diodes modules coupled to monomode fibers. The exit plane of the fibers is placed at the focal plane of the collimator. The fiber sources have a size of 4µm and an NA of 0.12, meaning the divergence is 6.9º, enough to cover the complete entrance pupil of the optical system under test (Fig 3.1-1a). The selected sensor is a CCD camera with a small pixel size, which was AVT Stingray F-504B. (Fig. 3.2-1b). It is a 2/3" CCD sensor with 2452x2056 pixels and a square pixel size of 3.45µm.

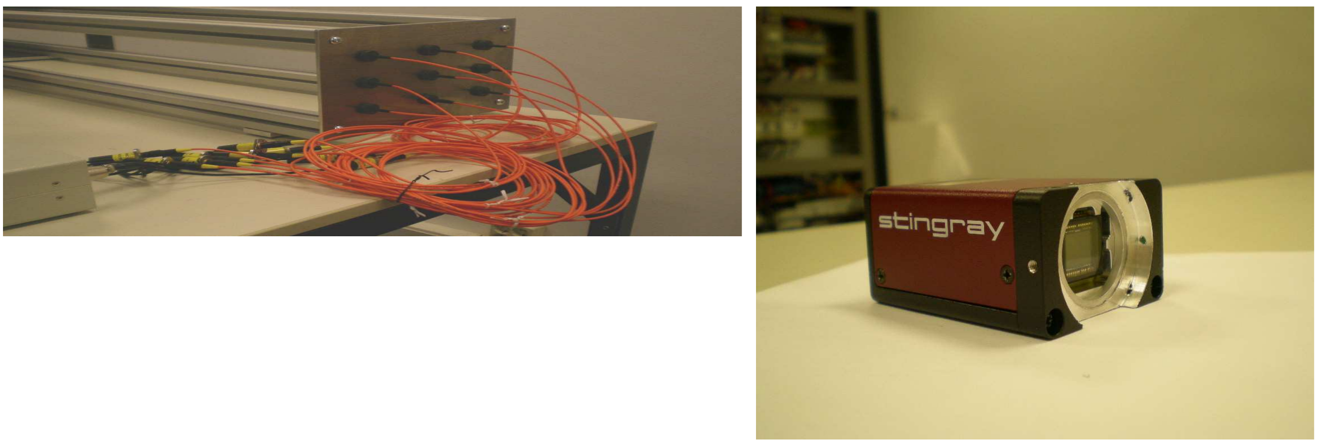
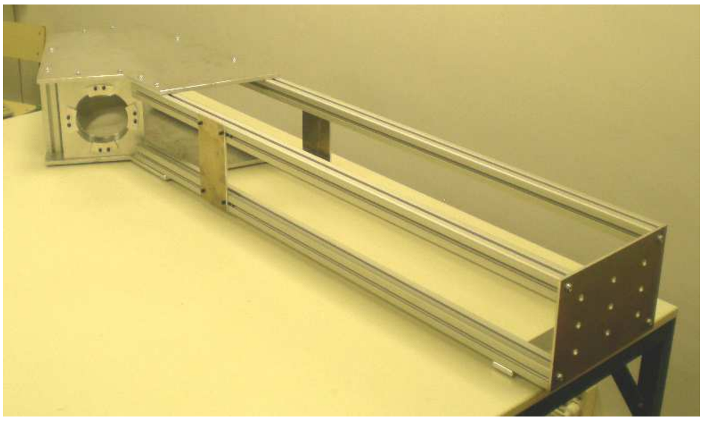


Fig. 3.1-1: a) Pigtailed laser diodes used as objects to obtained field PSFs; b) CCD sensor used (Stingray F-504B)

3.2 Mounted system

Aluminum mechanical supports were used in order to provide mechanical stiffness to the full instrument, and the supports for the different optical components involved (optical system under test, camera mount) were designed and implemented. Fig.3.2-1 shows the mechanical part of the instrument, including the folded optical path to give compacity to the instrument and the camera and optical system mounts. Fig.3.2-1 a) shows the complete optical path of the instrument, while at b) further detail in the mechanics for supporting the optical system under test and the camera are presented. The complete system may be seen in Fig.3.2-2, both prepared for testing and at work.

(a)



(b)

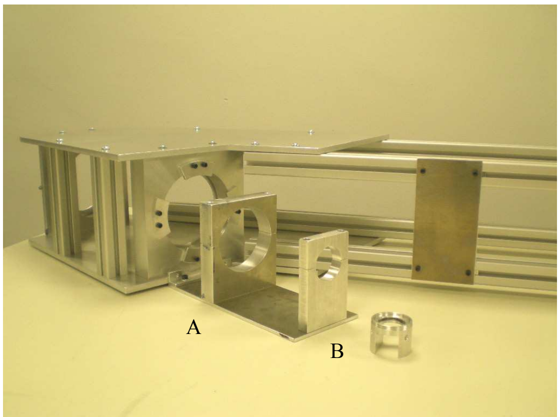
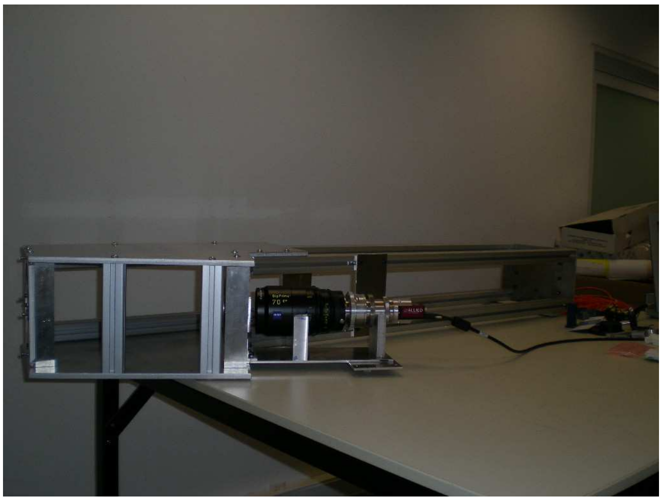


Fig.3.2-1 a) Complete mechanical structure of the folded optical system; b) Detail of supports for optical system being tested (A) and camera (B).

(a)



(b)

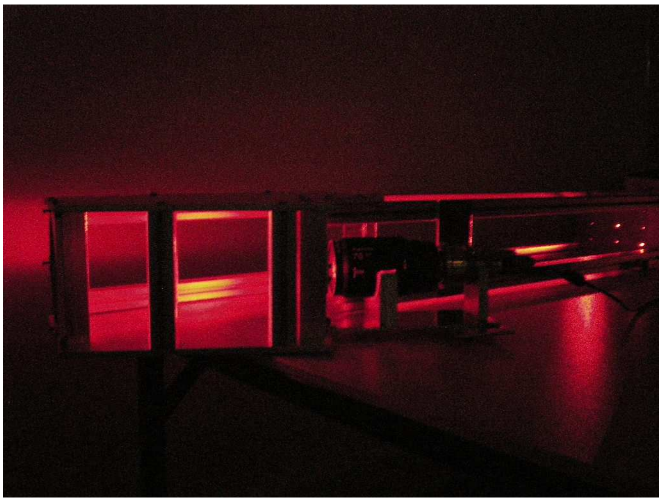


Fig.3.3-2 a) Complete optical system prepared for control of alignment; b) Tool at work; notice the 3x3 array of sources.

4. RESULTS/ANALYSIS

As a first step, a fine-tuning of the performance of the workbench was performed, mostly consisting in image focusing without any optical system included in order to ensure the performance of the components prior to testing. Next, an anamorphic optical system was included in the workbench to be tested. A second adjustment of the distances to compensate for the deviation of the system under test from nominal focal length was performed. Figure 4-1 shows the change in the image of the source plane, and the change in the shape of the central PSF, before and after the focal plane adjustment procedure.

(a) (b)

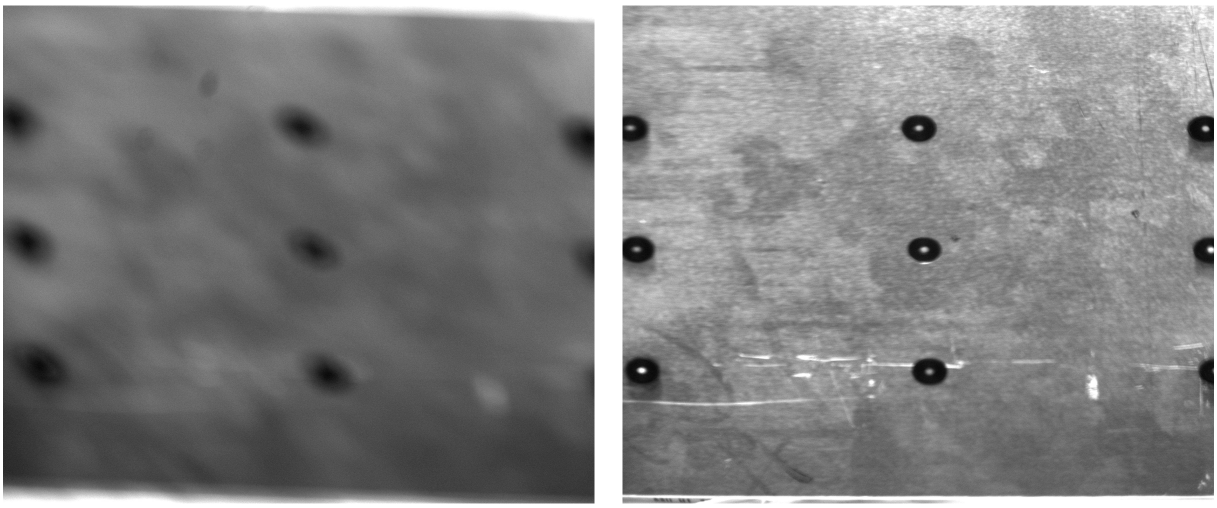


Fig.4-1.a) Image of the source plane before BFL adjustment; b) Image of source plane after BFL adjustment; c) Central PSF before BFL adjustment; d) Central PSF after BFL adjustment

Once the BFL was adjusted, the recorded PSFs obtained are presented in fig.4-2. It may be observed how an important lack of symmetry appears, in difference with the more symmetric patterns of fig.2-5. Moreover, only one of the anamorphic lenses could be accessed for modification for practical reasons. Although this was a problem for the automatic algorithm indicating how the lenses should be oriented, the global evaluation of PSF shapes was still very useful for the operator, as far as it provided a very clear tool for optimizing the inclination of the anamorphic lenses. Work is currently in progress in order to provide a precise automated estimation of which is the lens introducing the main effects, and on how it should be aligned or oriented. At present, a tilt of 3º of the first anamorphic lens in the system allowed a clear enhancement of the quality of the PSF images (fig.4-3) thus showing the validity of the approach. The pixel size of the PSF images has been kept equivalent to make images comparable.

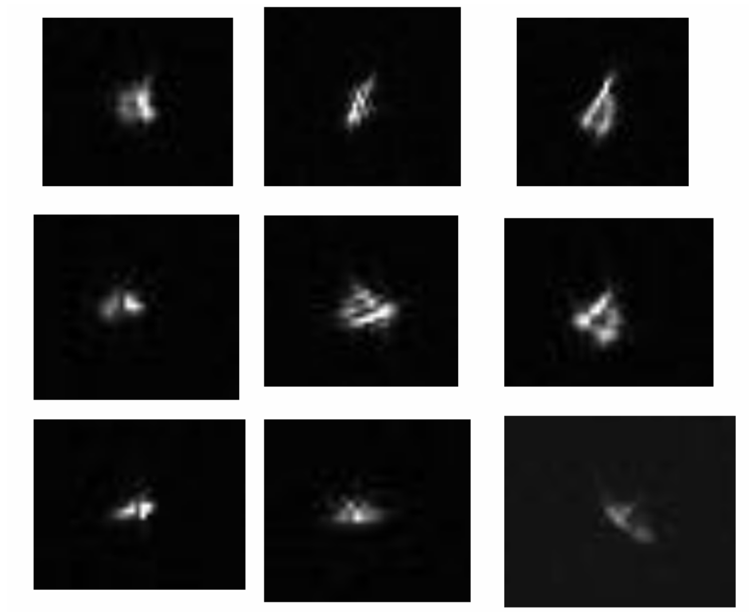


Fig 4-2: PSF images for the anamorphic system prior to adjustment of angle in the first cylindrical lens

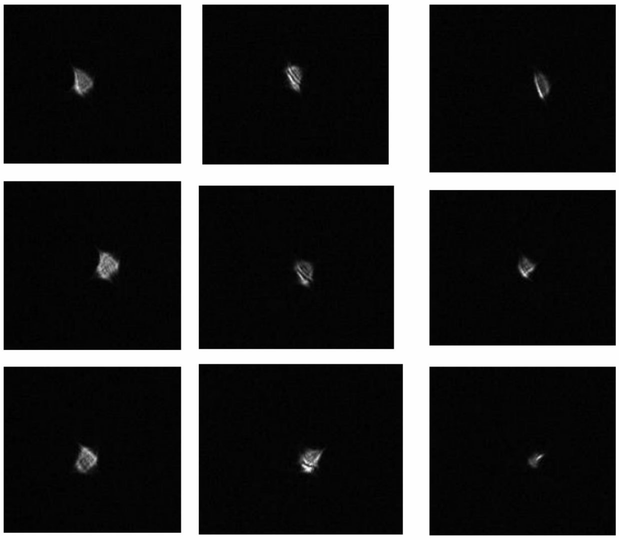


Fig 4-3: PSF images for the adjusted anamorphic system

5. CONCLUSIONS

A high-precision method for precise alignment of optical components, allowing the detection of errors or tilts in positioning of the components of the optical system has been presented. The procedure has also shown to be very effective for orienting the axis of a non-rotationally symmetrical surface, either a cylindrical surface or a toric lens. The system analyzes the shape and position of a set of PSFs across an optical system based on a compound source formed by nine pigtailed laser diodes. The images of these laser sources are collimated, passed through the system being tested, and focused onto a CCD sensor using off-the-shelf, well characterized, optical elements. The comparison of the calculated PSFs with those finally obtained allows the elaboration of detailed procedures in final stages of alignment, prior to the sealing of lens groups in complex optical systems.

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