Instituto Nacional de Astrofísica, Optica y Electrónica.

REPORTE TECNICO

COORDINACION DE OPTICA

CONSTRUCTION OF AN IMAGE SHAPE TRANSFORMER

Por

Alberto Jaramillo Núñez, Octavio Cardona-Núñez, Alejandro Cornejo-Rodríguez, Pedro Técuatl Técuatl and Perla García-Flores

Diciembre 2013
Tonantzintla, Puebla

CONSTRUCTION OF AN IMAGE SHAPE TRANSFORMER

Alberto Jaramillo-Núñez, Octavio Cardona-Núñez, Alejandro Cornejo-Rodríguez,
Pedro Técuatl Técuatl and Perla García-Flores

Diciembre, 2013

Abstract

The construction is reported in this paper of an image shape transformer with optical components and commercial devices presently available. The corresponding theory of the shape transformer can be consulted in previous works.

Due mainly to the small dimensions of the transformer, of a few millimeters, many problems were found and resolved. We think it is useful to summarize this experience in this document, so, practical problems related with the optics, alignment, mechanics and mountings along the construction of the transformer are described in the next sections.

Introduction

The main objective of spectroscopy is to collect the maximum possible radiant power from a given source, and to disperse and detect it appropriately and efficiently. The slit spectrometers used in stellar astronomy consist of an entrance slit, a collimator, a dispersing element, a camera and a detector. The camera is used to demagnify and focus the slit on the detector. The image produced by the optical system or telescope on the entrance slit of the spectrometers is in general not a sharp point and the size is larger than the optimum slit width. This is a common problem in astronomical spectroscopy where the stellar image is distorted by the earth atmosphere, the seeing, producing in general greater images than the required slit width. For that reason the light lost is great and is necessary to change this problem specially if ones observe faint objects.

At INAOE, some efforts were started in this direction in 2006 for improving the light going into the spectrometer. As result of this effort a doctoral thesis [1] was done where one solution was proposed. In that work the solution is completely analyzed, but, none prototype was built. In this report we describe how to build a transformer, taking as reference such proposal and some parameters of the telescope of Cananea [2,3].

In this report it is described with details the work done during the construction of what was called an Image Shape Transformer (IST). The described problems are related with mechanical design together with assembly and measurements of the decentering. The decentering problems are shown by means of some calculated graphs.

Construction

The IST consists of two cemented optical elements, the first is a plane convex lens and the second one is a plane parallel plate (PPP). Fig. 1 shows the dimensions of those optical elements.

First, we ought to build a larger IST to analyze some problems that could arise during the construction of the IST. The first built IST was compound by a lens with a diameter of 5 mm, a PPP of 25 mm wide and 1 mm of thickness, typical dimensions of a microscope slide. For both optical components an aluminum mounting was designed and its conceptual design is shown in Fig. 2. As one can appreciate, the design consists of a piece with a bore and a rectangular groove. However, for practical reasons, the design was rejected by worker in charge of the machine tool, his argument was that the groove can not be done by a common milling machine.

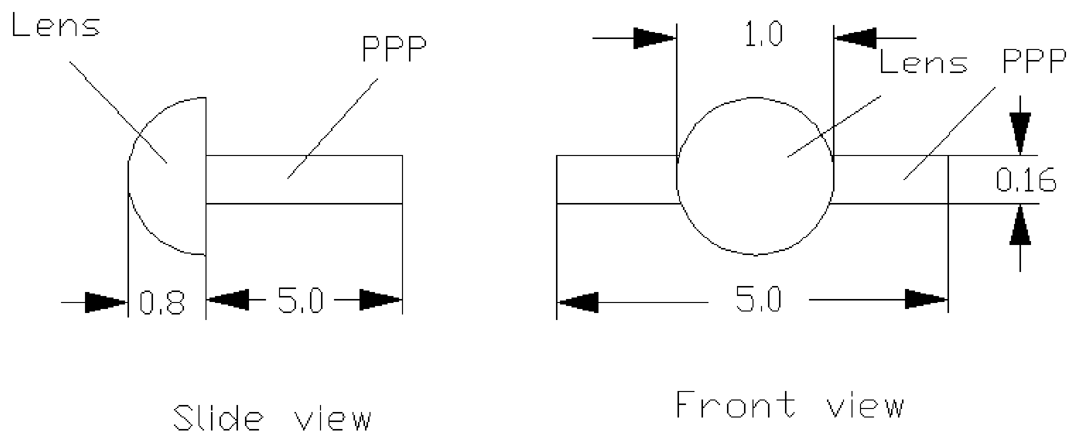


Fig. 1.- Dimensions of the optical elements of IST.

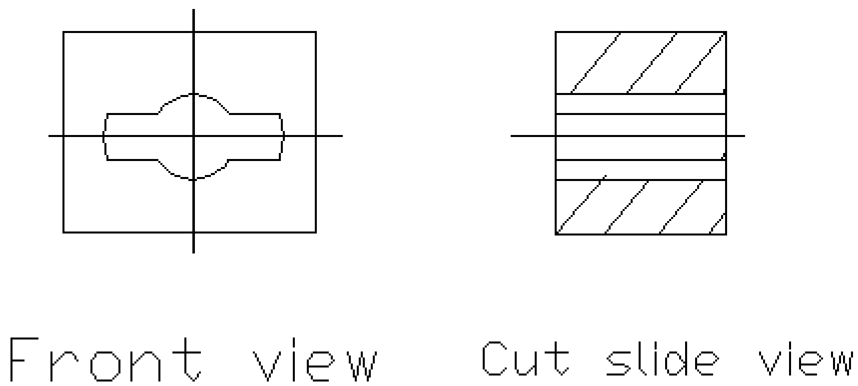


Fig. 2.- First conceptual design of the mounting.

Thinking that the rest of the design was viable, we decide to make a new mounting divided in two parts, option that was accepted by the worker of the milling machine tool. After the groove is made on the piece *a* (see Fig. 3), for example, the parts *a* and *b* are assembled by means of a couple of screws, lastly the bore is made, which is not shown in Fig. 3. The new design and its dimensions are shown in Figs. 3 and 4, respectively.

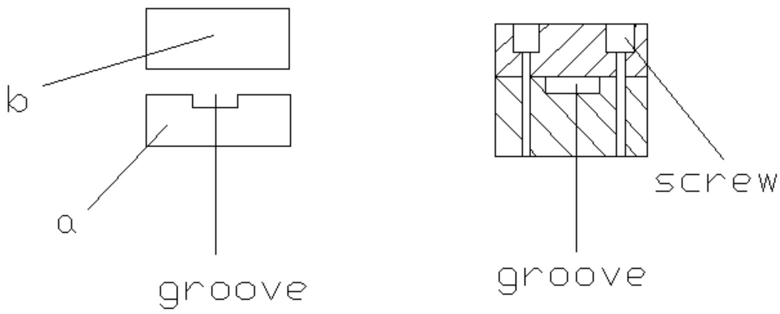


Fig. 3.- Second conceptual design.

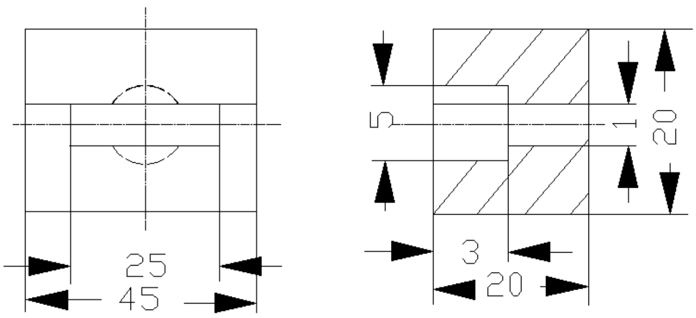


Fig. 4.- Mounting to build the first IST.

The mechanical mounting was made in the mechanical shop of INAOE. Before constructing the mounting, two tests were made. One failed due to excess of adhesive in cementing the lens and the plate, therefore, it is necessary to be careful during the application of adhesive. Mechanical mounting, optical elements and built IST are shown in Fig. 5.

After building the two IST, we decided to make the required IST. The lenses used have a diameter of one millimeter and a focal length of 0.6 mm; they were bought from Edmund Optics with stock number M45-588 (catalog 2011). To obtain the PPP were difficult because to build them from commercial slides was not possible, given that the commercial glass slides are nonhomogeneus, showing some scratchs and porous. This was verified by observing the polished front and back surfaces on the glass slide with a microscope. In the optical shop of INAOE it was not possible to make such a kind of glass slides, since they do not have the appropriate machinery for the required dimensions.

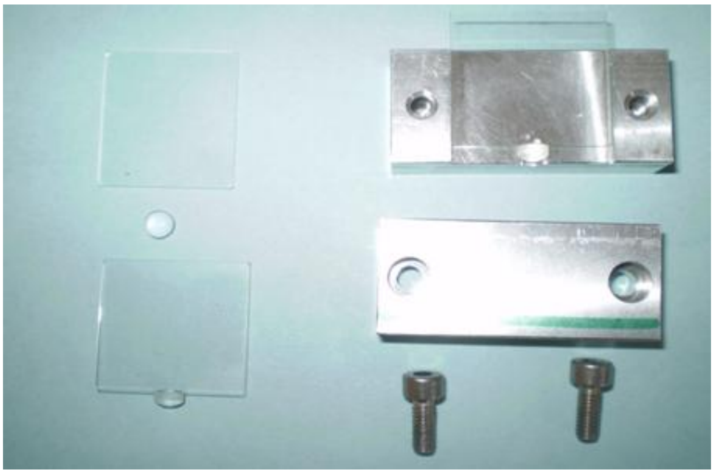
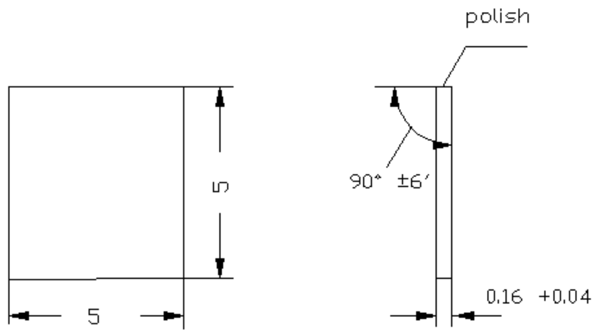


Fig. 5.- Optical elements, mechanical mounting and prototype are shown.

It is possible to find suppliers of optical glass with the required characteristics but the problem is that they only sell big volumes, of the order of 1000 pieces or more, which is not economically possible for us right now.



Notes:

Material: BK7

Dimensions: in millimeters

Tolerance: ± 0.1

Flatness: 5 λ

Fig. 6.- Dimensions of the PPP.

The way we solved the problem was to request six pieces to the Center of Investigations in Optics (CIO). They charged 12 000.00 pesos for the construction, with a delivery time of one month. Fig. 6 shows a scheme of the requested PPP. As one can appreciate the tolerances are relaxed except in the thickness.

To build the required ISP we need another mounting with appropriate dimensions to place the optical elements. Following the same concept of the previous mounting to build the first prototype, a second one was built, also at the mechanical shop of INAOE. The design is shown in Fig. 7 and as one can observe a change was done with respect to the previous design. The new design has an additional piece with two bores and one step (see Fig. 7.a). One bore is a guide for the lens and the second one is to screw the pieces as shown into plane in Fig. 8. This change in the design allow us that the final assemble (see Fig. 8) conserves their flatness. Also, this additional piece has a step which was made with the purpose that when the piece is screwed, automatically the guide bore is centered respect to the groove.

Alignment

In this work three alignment methods can be used. The first, called ideal method, can be carried out by means of a exact rays trace by using a software of optical design (see Ref. 1); the second is an optical method, carried out in a laboratory, by observing interference patterns; and the third is a mechanical method.

The ideal alignment is impossible to carry out since it is not possible to observe the rays that leave the system, although it will be useful as we will show later on. Due to the dimensions of the IST is laborious to carry out the optical alignment because we don´t have appropriate mounting for optical elements of these dimensions; besides it is impractical, since after the alignment it is necessary to carry out the process of cementing the optical components and is necessary to separate them from the mechanical parts, and consequently the alignment is lost. Due to the problems mentioned we decide to make the mechanical alignment.

The mechanical alignment was done following the next steps: First, by means of a reticle placed in a microscope, the width of the groove and the diameter of the guide bore were measured (see Fig. 7). Next, the pieces were assembled and the centers of the bore and the groove should coincide, approximately (see Fig. 8). Lastly, by using a reticle again, the width of the groove and the diameter of the guide bore were measured simultaneously in the assembled mounting to know the decentering error among both axes. This error was of 10 microns (see Fig. 9.c) which was considered a permissible error.

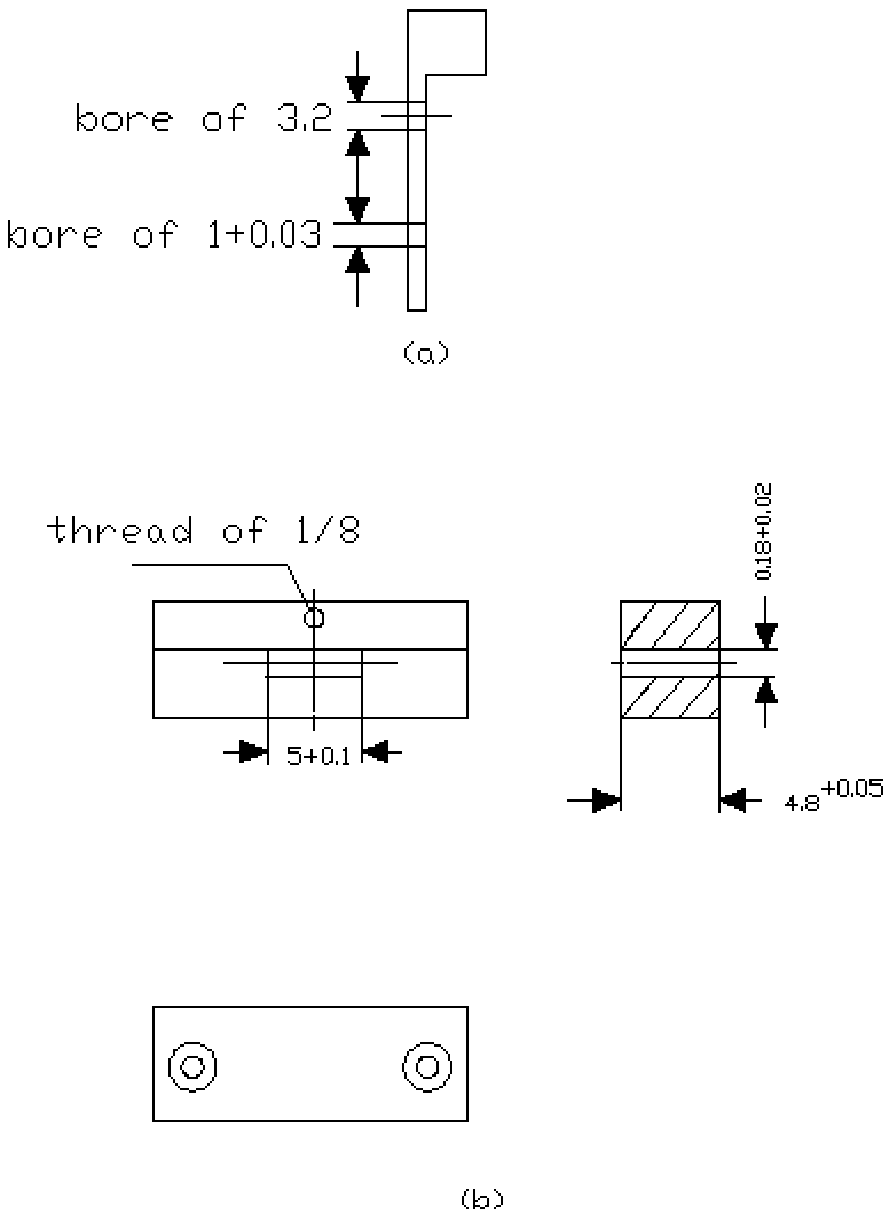


Fig. 7.- New mounting to assemble the IST.

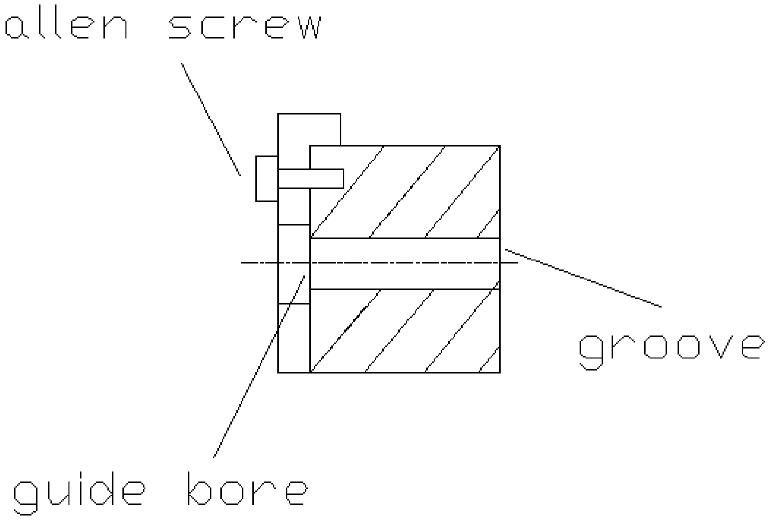
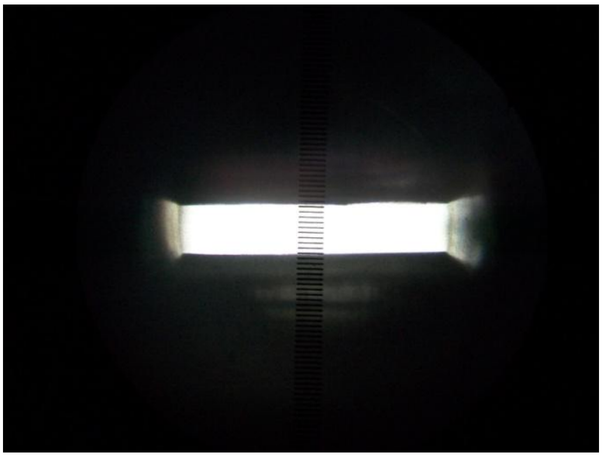


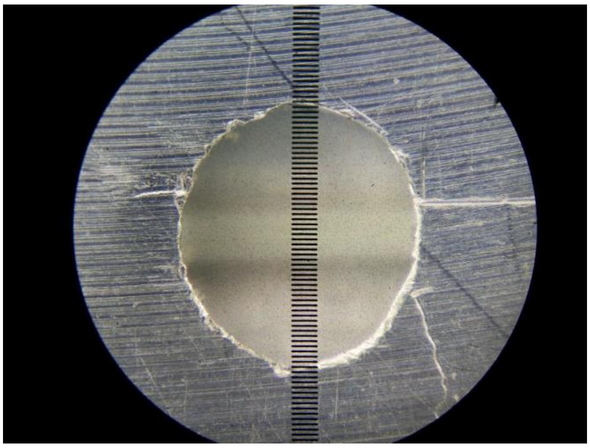
Fig. 8.- Assembled mounting.

Using the mounting shown in Fig. 8 a prototype was built.

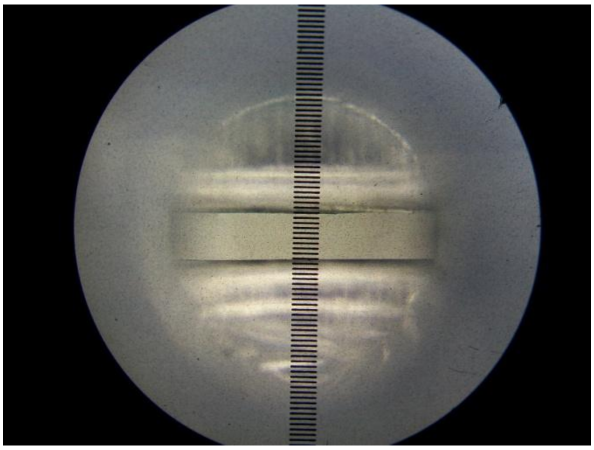
Other two IST, using a reticle and centering the lens by hand, were made; however, this process did not show repetibility, the introduced errors in the alignment were less than 40 microns. This descentering was mainly due to the use of a reticle that has 50 microns precision. If a reticle with better resolution is used; it is possible to diminish the 40 microns. In Figs. 10 and 11 are shown graphs with exact rays trace for the cases centered and decentered forty microns. For the decentered case the exit beam is contained in a thicker cone with respect to the centered case.



(a)



(b)



(c)

Fig. 9. – Measuring the decentering, a) measurement of the width of the groove, b) measurement of the diameter of the bore and c) simultaneous measurement of the width of the groove and diameter of the bore.

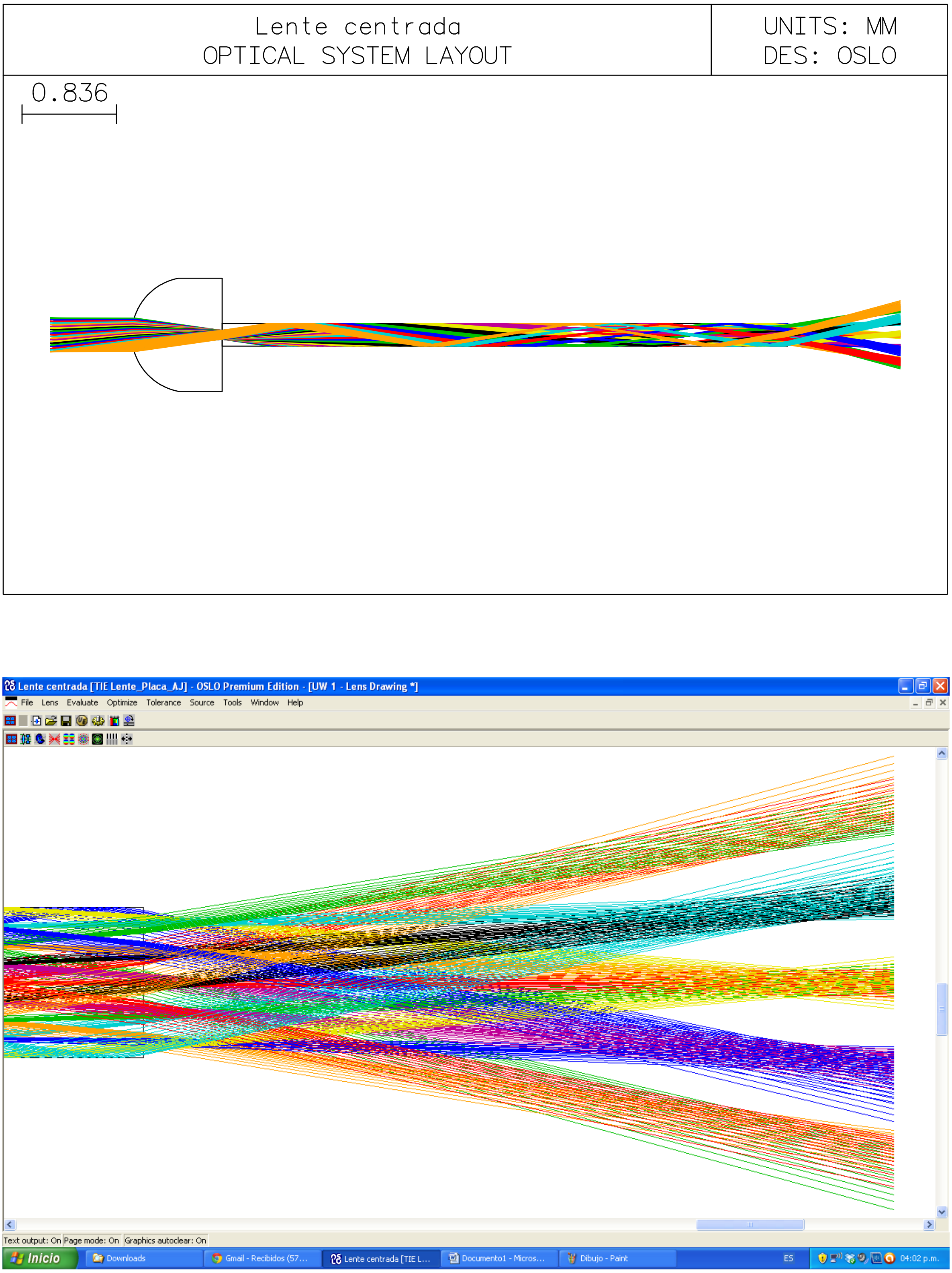
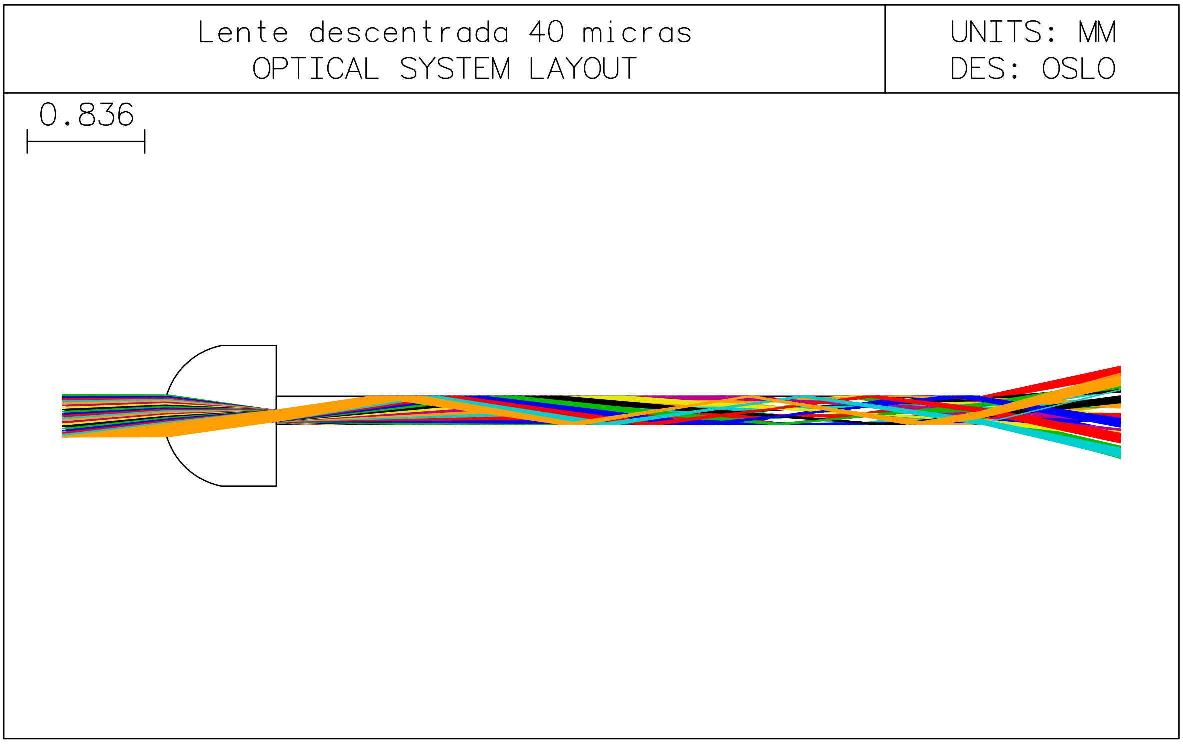


Fig. 10.- Ideal case.



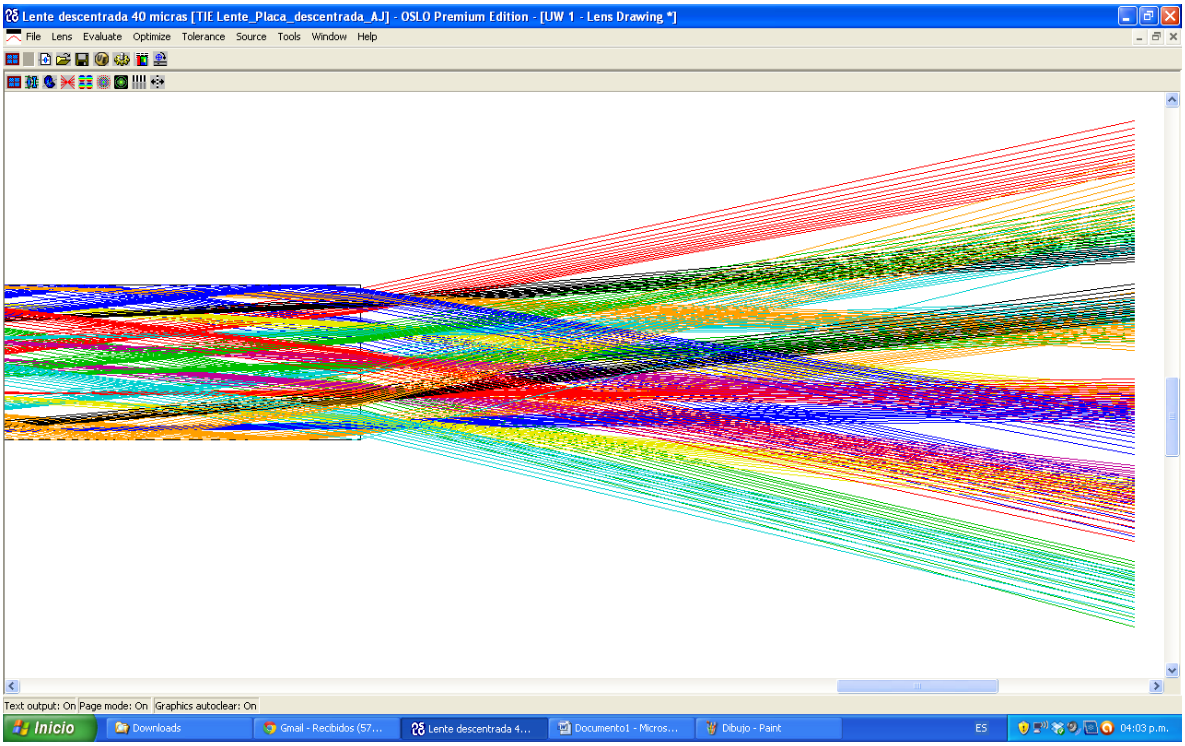
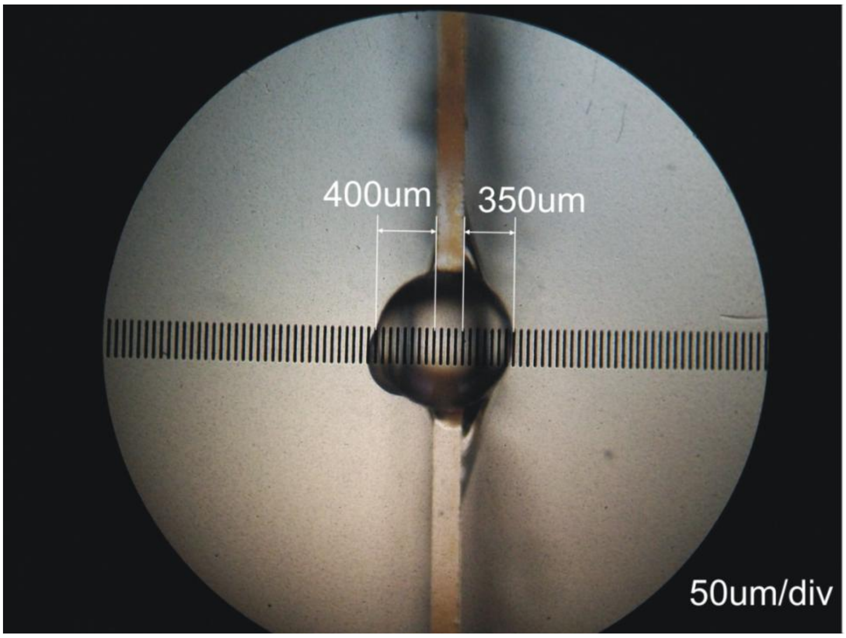


Fig. 11.- Real case. Decentered lens 40 microns respect to width of the slide.

Figs. 12 and 13 show the obtained results for the case of the two IST built manually. For the case of the two IST built manually the measuring of the decentering error was made with a microscope and with the aid of a reticle. As you can appreciate there is a cement excess on the optical elements again.



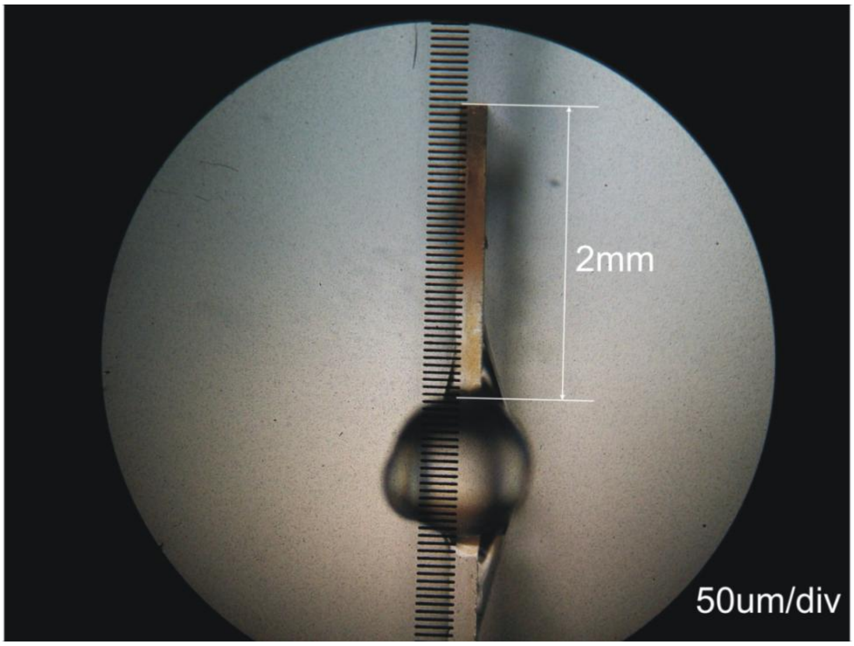


Fig. 12.- The decentering of the lens respect to width of the slide is 25 microns and respect to large is 0 microns.

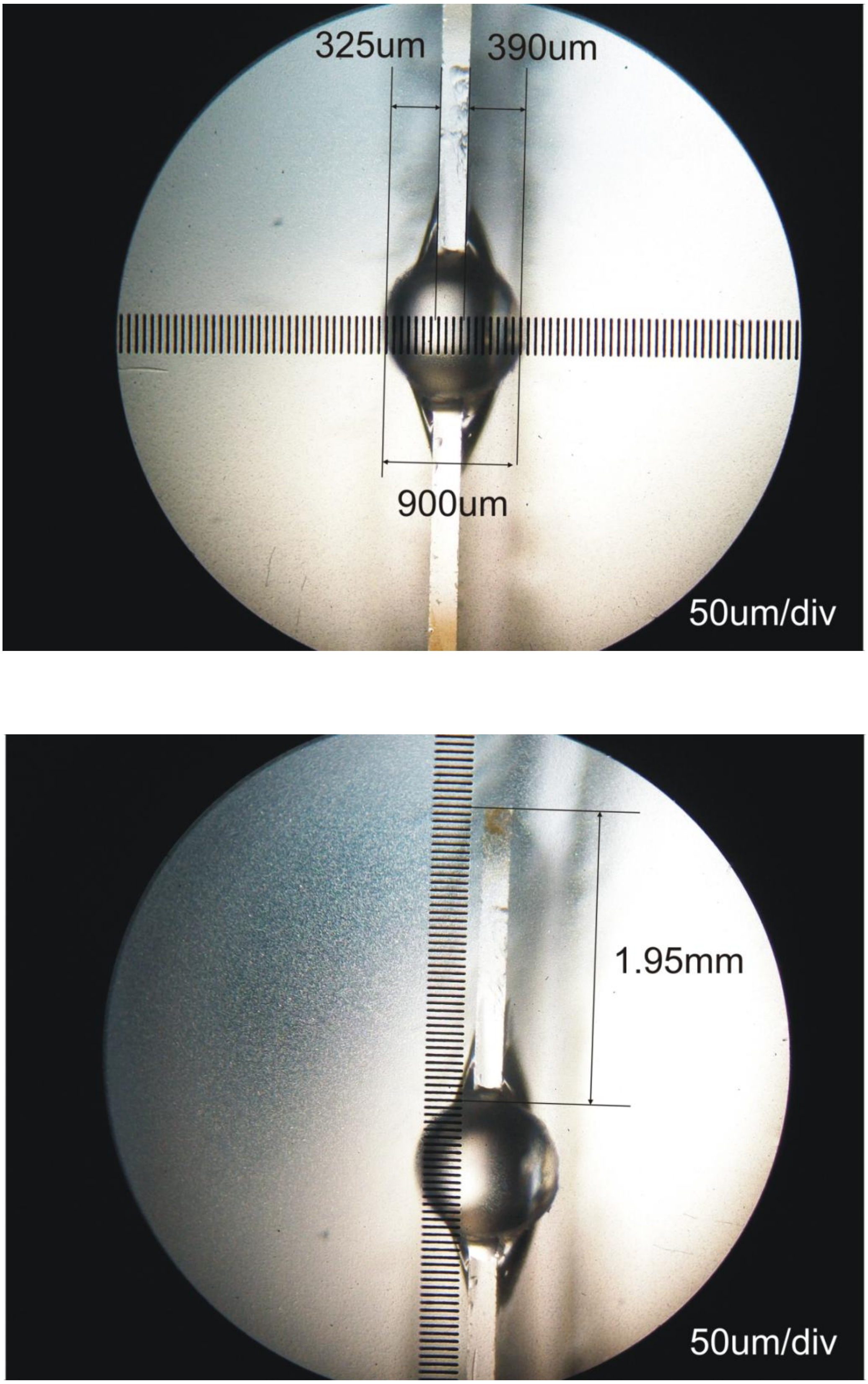


Fig. 13.- The decentering of the lens respect to width of the slide is 33 microns and respect to large is 3 microns.

Assemble

A scheme of the mounting used to assemble the IST is shown in Fig. 14. The design was thought to fulfill two objectives, the first one is to hold the IST and the second to facilitate assemble with the rest of the mounting that contains the additional optics. The way of fixing the IST to the mounting is the next part. First, a thin film of cement is placed on the right side and around of the guide bore. Next, the lens of the IST is pressed against the cement. Before cementing the pieces, the back surface of the lens of the IST was painted of black to avoid the introduction of nonwanted light

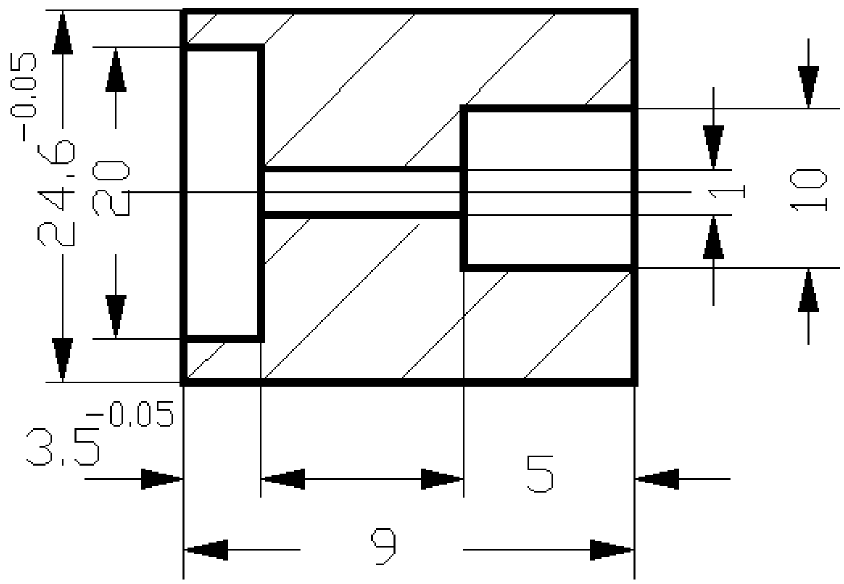


Fig. 14.- Mounting to fix the IST.

Since it is necessary to give a specific application for the IST, in this case the IST is to couple it to the telescope of the Observatory Guillermo Haro [3] based in Cananea, this must go accompanied by other two plane-convex lenses with a diameter of 3 mm (stock num. C45-117, catalog 2011 of Edmund Optics). Thinking in a good presentation and functionality of the IST, the design was made by using mountings that could be obtained easily in a catalog. For the case of the lenses of 3 mm of diameter (f = 3.0 mm) a mounting with stock num. C54-611 was selected and for the lens de 1 mm (f

= 0.8 mm) of diameter a mounting with stock num. C54-630 was selected, both of catalog from Edmund Optics.

The separations among the lenses depend mainly of the characteristics of the telescope and the spectrometer to be used. So, the design was also thought to accept changes in these separations by means of spacer rings and extension tubes. Edmund Optics sells a spacer ring kit (stock num. C54-461) and extension tubes kit (stock num. C54-668) by means of which is easy to obtain any separation in multiples of 0.25 mm. Fig. 15 show the assembled IST. In this case, the right side of the slide is in contact with the mounting of the lens that it is in the center of the assemble (the separation among the right side of the slide and the plane surface of the lens of the center is one millimeter). If a bigger distance among these two elements is needed one must use spacer rings just as is shown in the same figure. The rings and tubes can be coupled perfectly to the previously mentioned mounting since they are threaded. In Fig. 15, one can observe in the ends of the assemble two pieces which only work as overcoats. They should be retired when the transformer was used.

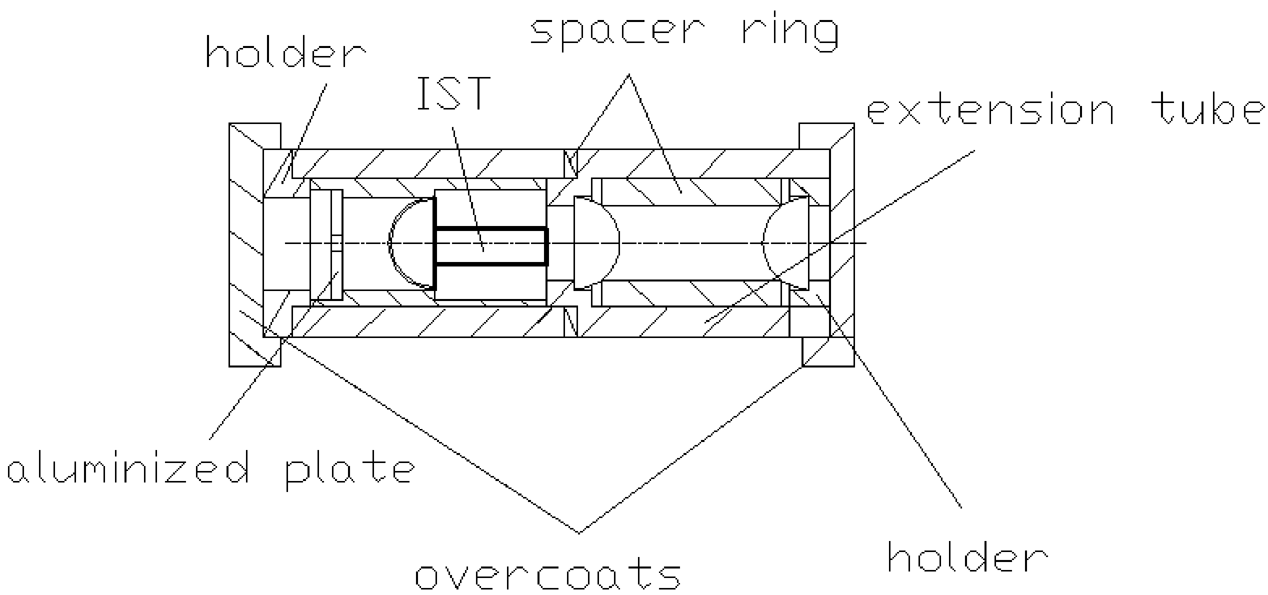


Fig. 15.- Assembled IST.

To facilitate the entrance of the light beam into the IST an aluminized glass plate was placed on the left part. The design shown in Fig. 14 is calculated for a glass plate of one millimeter of thickness in such a manner that a distance of 0.75 mm exists among the lens vertex of the IST and the reflecting surface of the plate.

The dimensions of the built IST are 40 mm long and 30 mm of diameter.

Fig. 16.- Built IST

3 Analysis

3.1 Using a laser beam

To find the interference pattern observed on the exit face of the IST we use the physical optics and Fig. 3. We suppose that a convergent spherical beam is introduced into the PPP by means of a free aberrations lens, in such a way that the beam is focused in a point inside of the PPP. For simplicity, we will consider that the interference pattern is created for the superposition of the light coming from three sources, two virtual created by the surfaces of the plate and a real, formed inside the PPP.

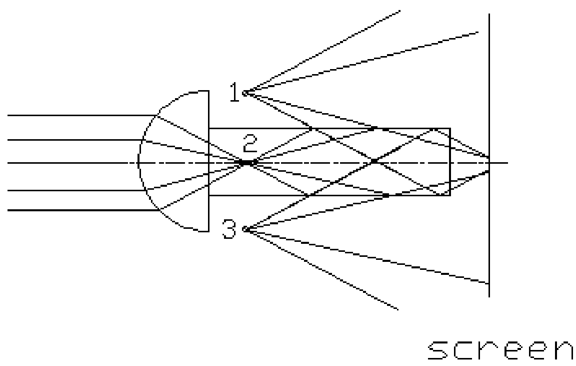


Fig. 3.- Setup of equivalent sources.

Considering the sources 1, 2 and 3 as punctual, mathematically we can express them as δ[x - (d/2)] + δ(x) + δ[x + (d/2)], where ***d*** is the distance among virtual sources, that is, twice the thickness of the PPP. It is not difficult to find that in some point ***p***(x,y,z) of the space the intensity is given, except for some scale factor, by

$$I(x,y,z) = 1 + 4cos^2\left(\frac{\pi x d}{z\lambda}\right) + 4cos\left[\frac{\pi}{z\lambda}\left(\frac{d}{2}\right)^2\right]cos\left(\frac{\pi x d}{z\lambda}\right) \quad (1)$$

The pattern obtained using Ec. (1) is shown in Fig. 4.

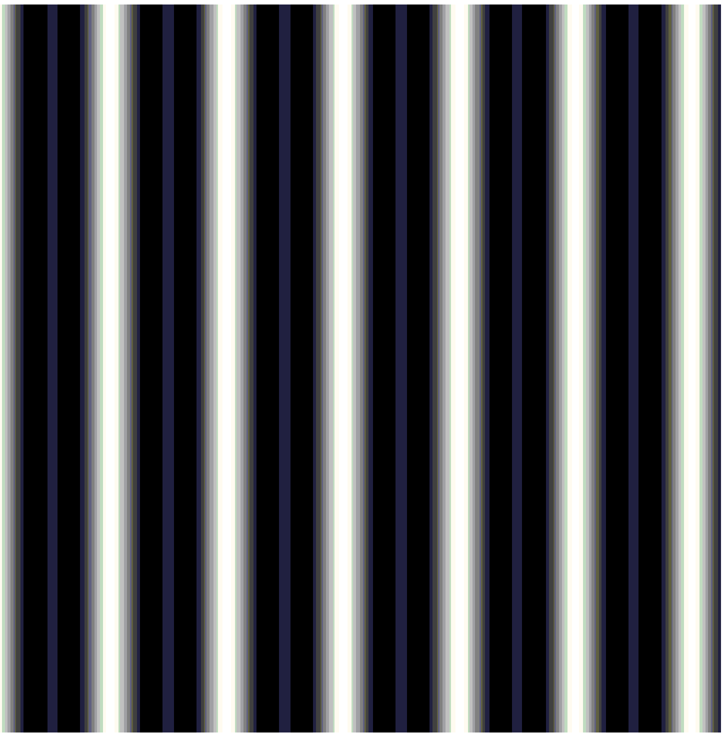


Fig. 4.- Interferogram obtained using Eq. (1)

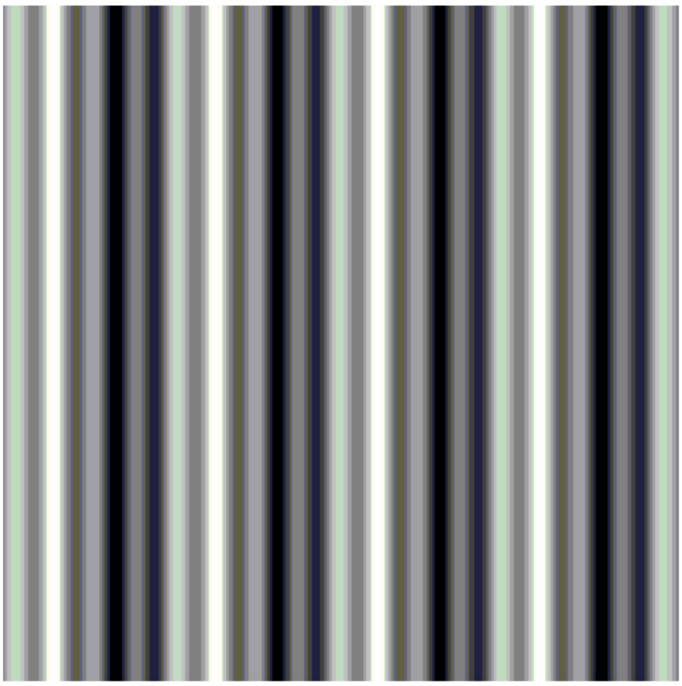
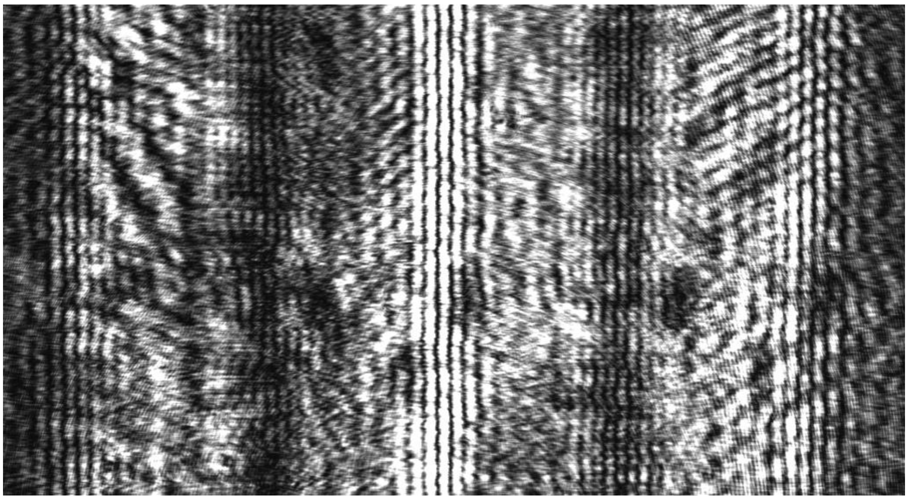


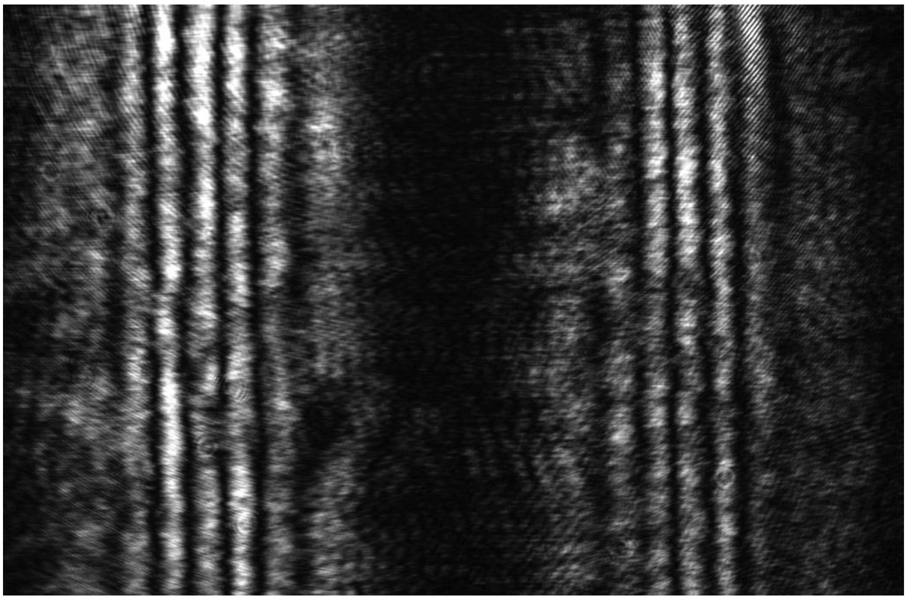
Fig. 5.- Interferogram obtained using tree plane waves.

However, when the PPP is large compared with its thickness, the interference pattern could be formed due to the superposition of plane waves, in that case, would take the form shown in Fig. 5. To calculate the patterns showns in Figs. 4 and 5 it was considered that the source is on the earlier surface of the PPP and the pattern in the later surface, that is, z = 5 in Eq. 1.

Fig. 6 shows the pattern obtained experimentally and as can be observed it seems at shown in Fig. 5.



(a)



(b)

Fig 6.- Interference pattern obtained experimentally, (a) complete and (b) a section (contrast has been reduced).

3.2. - Consequences due to the misalignment

When the lens is centered with respect to the axis of symmetry of the PPP, the fringe of order zero of the pattern is centered respect to the axis of symmetry of the PPP also (to see Fig. 7.a). When the lens is laterally misaligned (see Fig. 7.b) the real source moves laterally, in such a way the fringe of order zero moves laterally the same quantity, but in oposite direction. When the real source has a longitudinal displacement the interference pattern is displaced longitudinally too the same quantity, but no change can be appreciated.

Exist another case of interest and it is when the source is centered and the surfaces are outside of parallelism for an very small angle $\boldsymbol{\theta}$, that is, $\boldsymbol{\theta} << 1^{o}$. In this case the pattern has a longitudinal and traverse displacement simultaneously. The pattern's displacements due to the non parallelism of the DPI are reported in the literature and they are given for [4, 5]

$$z(\theta) = \frac{bl}{b+2l\theta} \tag{2}$$

$$y(\theta) = \frac{bl\theta}{b+2b\theta}, \tag{3}$$

where $\boldsymbol{l}$ is a half of the length of the plate and $\boldsymbol{b}$ is its thickness.

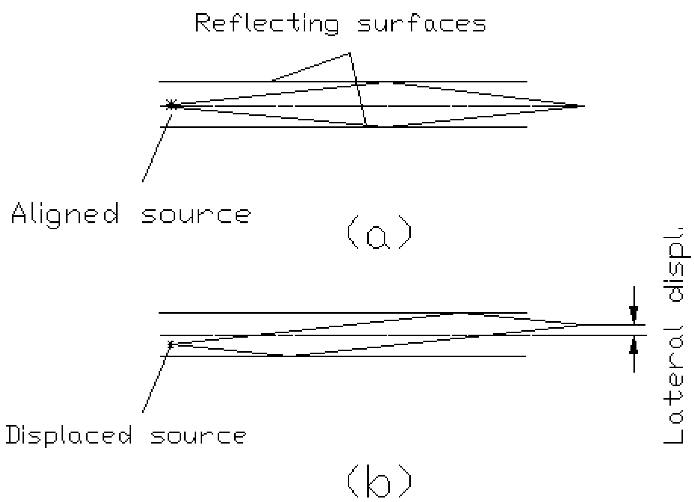


Fig. 7.- Possible positions of the source.

3.3. - Phenomena inside the PPP

One of the most interesting works that analyze the intensity distribution inside a LGP is of Bernabeu and collaborators [5]. They show that in a nonlinear mediums and in appropriate conditions nonlinear behavior can be obtained and these might become useful in order to obtain optical bistability. In a similar arrangement to the IST, alone that using a couple of plane and parallel mirrors, Jaramillo and collaborators [6] show that due to the superposition of three beams it is possible to obtain an interference pattern located in an zone of the space with rhombus form. This characteristic is also presented in the IST after the first reflection of the beam inside the PPP (to see Fig. 8). Before this area there are other two but due to interference of the two beams, among the beams 1 and 2, and 2 and 3, respectively. As the beam propagates, the number of reflections increases and this characteristic is lost, until being observed some of the patterns shown in Figs. 4 and 5.

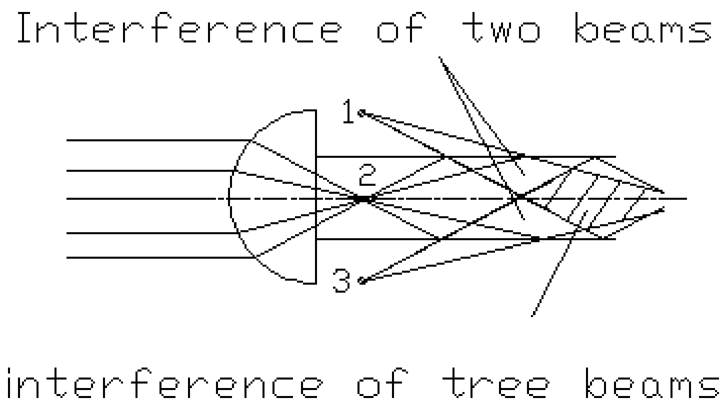


Fig. 8.- Interference zones near to the sources.

Conclusions

In order to carry out the construction of an instrument it is always required the participation of a group of persons with different abilities. In this case in particular, still when we started from an established design, we think that the construction work would be minimum, however, this was more laborious due to the dimensions of the IST. During construction, it was required a worker of machines tools, an opticians, an astronomer, a designer, and a technician devoted to the application of thin film. This is the only way that technological projects as this can be carried out.

The only thing that is necessary to improve to build a good IST is the technique of cementing since still after five intents too much cement was placed.

Acknowledges

We thank to the staff of the mechanical shop and especially to Saturnino Escobar Juárez and Javier Arriaga Petrona the aid to carry out the construction of the mechanical mountings of the IST.

References

1.- Perla C. García Flores, “Diseño de un transformador de imagen para espectroscopía”, Tesis de doctorado, INAOE, 2006.

2.- O. Cardona, A. Cornejo-Rodríguez, P. C. García-Flores, “Star image shape transformer for astronomical slit spectroscopy”, Rev. Mex. AA 46, 431-38 (2010).

3.- I. Furenlid and O. Cardona, “A CCD spectrograph with optical fiber feed”, Astronomical Society of the pacific 100, 1001-1007, august 1988.

4.- Alberto Jaramillo-Núñez and Erwin Martí-Panameño, “Interferómetro de dos superficies planas reflectoras”, Rev Mex Fis 38(4), 638-642, 1992.

5.- Alberto Jaramillo-Núñez, “Interferómetro de dos superficies planas reflectoras”, Tésis de licenciatura, Fac. de ciencias Físico-Matemáticas, BUAP, 1990.