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IMAGE QUALITY OF AN OPTO – MECHANICAL SYSTEM DEPENDING ON STRESS AND STRAIN STATE

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Abstract: This paper is an analysis of image quality parameters variance for an achromat doublet, in several loading cases. The results of the study allow the emergence and evolution of the phenomenon of birefringence and its correlation with the size of the additional strains of wave front. The stress state, especially the strain state indicates deviations from spherical diopter caused by mechanical stress. The quality evaluation of optical system with aspherical diopter analysis was performed with the program dedicated optical systems OSLO LT. Assessments on reducing the linearity of the optical system on certain areas of the aperture were made and conclusions about the influence of mounting even on an ideally positioned optical system.
Keywords: Lenses, stress and strain state, OSLO LT software, birefringence phenomenon

1. INTRODUCTION

Establish the stress and strain of the optical elements subjected to different values of external stresses, as a result of the mounting, allows the variation image quality parameters [1], [5], [6], [7], [8]. It is highlighted the fact that the entire study took into account an opto - mechanical system without mounting errors, in the optical subaassembly's elements occupy a nominal position unaffected by the uncentering or canting elements. For this study, the diffraction limited doublet's OPD RMS synthetic quality indicators and Strehl ratio were determined, and for image quality evaluation OSLO LT program was used [9].

2. THE ANALYSIS OF IMAGE QUALITY PARAMETERS VARIATION

Two phenomena are going to be analyzed:

- consecutive birefringence of a stress state in optical elements
- diopter strain due to the nodal displacements of the structure

Table 1 presents data referring to birefringence effect of the piece's straining for the converging lens [2], [4].

Table 1. Data referring to birefringence effect of the piece's straining for the converging lens

p [MPa]	$\sigma_{Mises\ max}$ [MPa]	Δs [nm/cm]	OPD_+ [nm]	RL_+ [-]
10	6.0	166.2	83.1	0.60
5	2.7	74.8	37.3	0.27
2	0.9	34.0	17.0	0.12

On each line external load values (approximately equal to the maximum von Mises stresses,) can be seen, the optical path difference introduced by the considered stress, the effective optical path difference and Rayleigh criterion value corresponding to OPD caused by birefringence.

For the studied material, BK7, for which the optical stress coefficient is $k = 2.77$ and for the reference wavelength $\lambda = 546$ nm (e spectral line), OPD has the value $\lambda/4$ of Rayleigh criterion corresponding to the external contact pressure $p = 5$ MPa. It follows that, in terms of birefringence, the optical subassembly's compressing force must be limited so that the equivalent von Mises stresses [3] shall not exceed 5 MPa.

Although additional OPD introduced through the birefringence effect stack with the residual OPD of the design system, it is considered that the previous prescription is covering due to the fact that the maximum stress value was taken into consideration (valid for the external zone and much diminished in the central zone of the lens) and also that the maximum thickness calculation was introduced at the center of the component.

As it concerns the second aspect of changing the spherical initial shape of the diopters, it appears that the subassembly's stressing creates displacements which lead to diopter aspherization.

The X and Y initial coordinates belonging to the circular generating curve move in a meridian plane. The absolute values of the displacements are $1\cdot10^{-4} \ldots 3\cdot10^{-4}$ for the X coordinate (figure 1) and are lower for the Y coordinate (figure 2).
Although the movements are small in absolute value, they were unevenly distributed and this lead to overall strain of the diopter's surface, which requires an analysis of the subassembly's quality parameters.

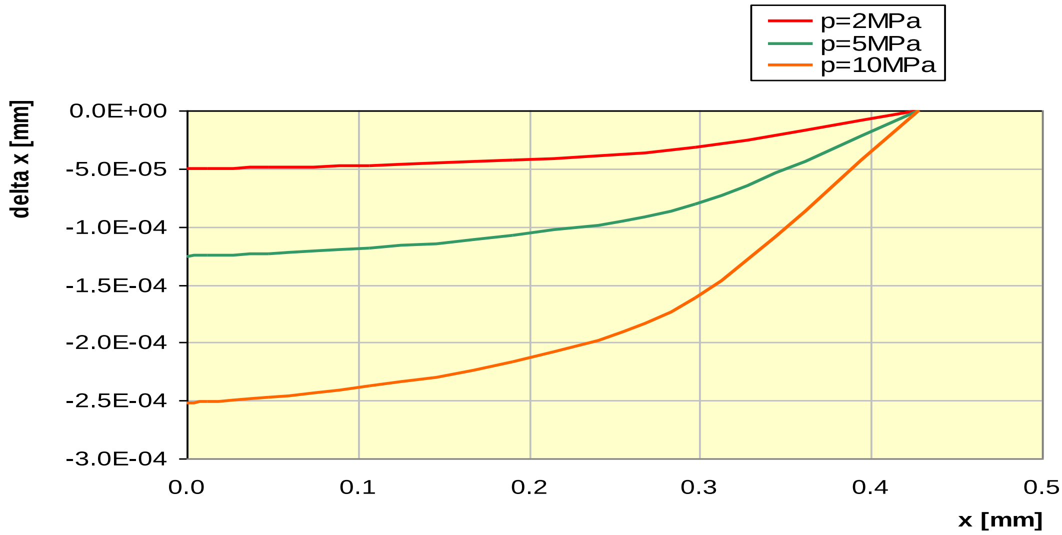

Figure 1. The axial displacements variation (along the optical axis) in relation to the aperture for external stress p = 2 MPa, 5 MPa and 10MPa

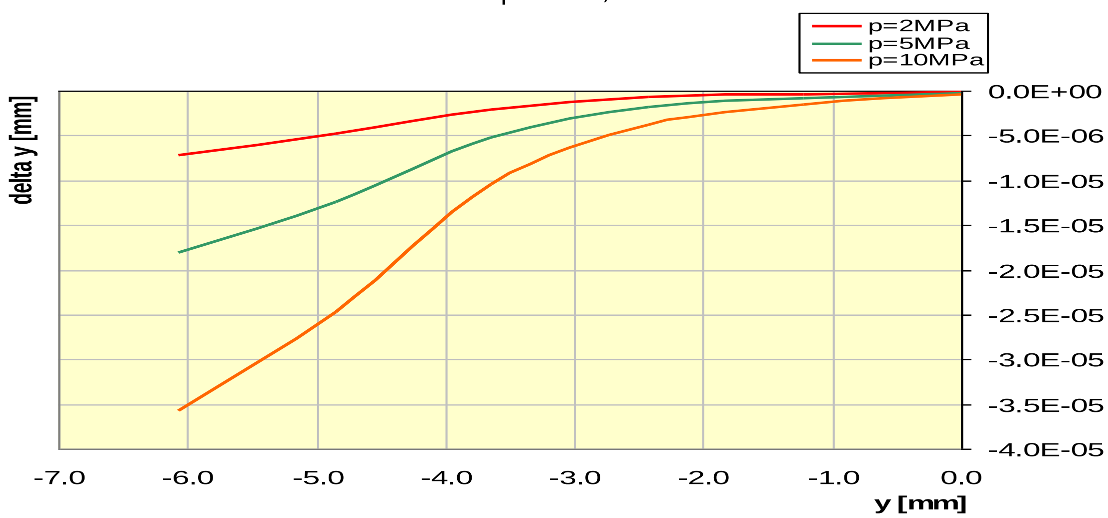

Figure 2. The axial displacements variation (along the Y axis) in relation to the aperture for external stress p = 2 MPa, 5 MPa and 10MPa

For the diverging lens on which the request is directly applied, the stress and strain effects are even more obvious.
Table 2 presents a synthesis of the data which characterise the birefringence effect.

Table 2. Synthesis of the data which characterise the birefringence effect

p [MPa]	$\sigma_{Mises\ max}$ [MPa]	Δs [nm/cm]	OPD_+ [nm]	RL_+ [-]
10	11.0	329.0	131.6	0.96
5	5.3	158.5	63.4	0.46
2	2.1	62.8	25.1	0.18

For the diverging lens whose material (SF 5) has a higher optical stress coefficient, k = 2.99, the recommendation limit of the equivalent von Mises stresses [3] have a value of 2 MPa.
Movements of the diopter's generating curve in a meridian plane are presented graphically compared to the aperture in figure 3 (for X coordinate) and 4 (for Y coordinate).
It is noted that the displacements in the x direction are up to 3 times higher, while the displacements in the y direction are up to 10 times higher than the converging lens. It follows that the most affected part, in terms of mechanic, is the component that comes in contact with the screw ring. It can be concluded that for a longer string of optical parts the tensions are taken mainly by the first components closer to the threaded ring. Tensions and deformations will be lower towards the end of the string.

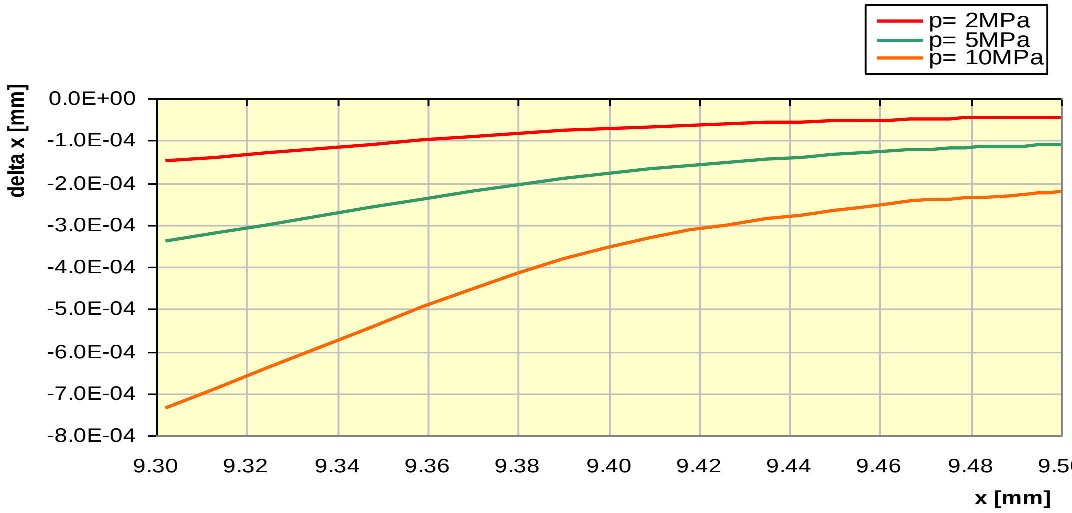

Figure 3. The displacements variation along the optical axis in relation to the aperture for p = 2 MPa, 5 MPa and 10MPa

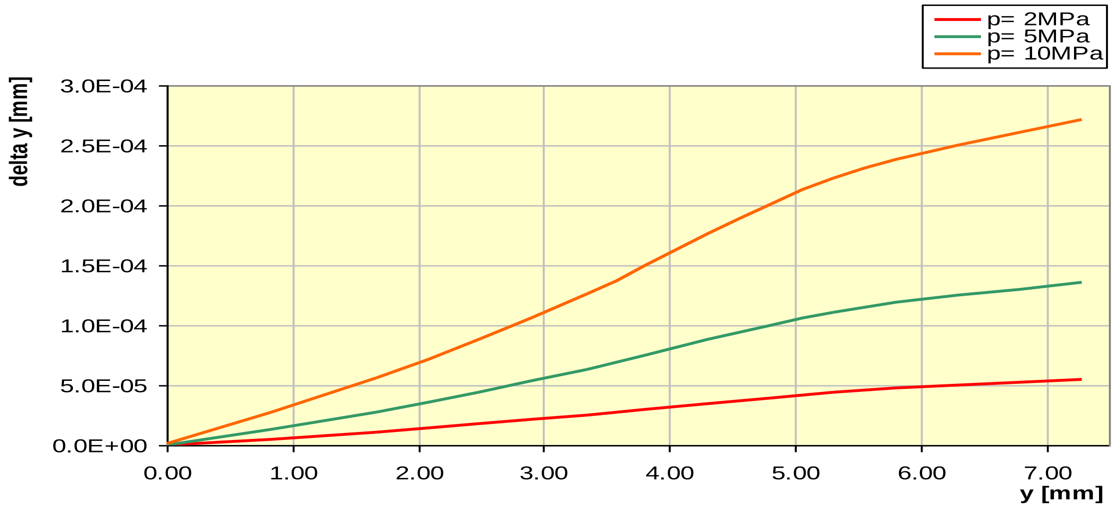

Figure 4. The displacements variation along the Y axis in relation to the aperture for p = 2 MPa, 5 MPa and 10MPa

In order to analyze aspherization influence on the diopter OSLO LT program was used.

Table 3 presents a summary of the results from asherization simulation.

Table 3. Summary of the results from asherization simulation

p [MPa]	k_{conv}	k_{div}	D=14 mm		D=12 mm		D=10 mm		D=9 mm	
			RMS	Strehl	RMS	Strehl	RMS	Strehl	RMS	Strehl
0	0	0	0.0528	0.9064						
2	-0.69	-0.43	0.0747	0.8028	0.0489	0.9116				
5	-1.73	-0.56	0.1591	0.3533	0.0898	0.7166	0.0481	0.9109		
10	-3.47	-0.75	0.3112	0.1257	0.1704	0.2983	0.0849	0.7393	0.0574	0.8722

The data study from table 3 allows a nuanced analysis of image quality parameters evolution relating to the compressing force applied to mechanical fastening components.

In absolute terms, diopter asphierization damage image quality. It is emphasized that, from its design, analyzed system it is limited to optical diffraction as shown in the first row of the table (the filling color yellow is associated to the system's classification in the highest quality class).

On the second line, corresponding to p = 2 MPa, at the designed aperture, the optical system descendes to a precise system category. The linearity and the limited to diffraction are kept on a reduced area corresponding to a 2 mm smaller aperture. In other words, the system is diffraction limited to only 85% of the maximum aperture.

For larger applications, when p = 5 MPa and p = 10 MPa, linearity system is restricted to 70%, respectively 65% of the maximum field.

Comparing birefringence effects and the global change form of the diopter it can be said that the latter is more significant in terms of influence on image quality. In terms of materials strength, it comes out that strains are more important than stress. The stresses were low, which is not a probable cause of destruction. Safety factor exceeds 10 compression value, since the starting force compression fracture is 100MPa. The stresses should be limited due to the strains accompanying them. From this point of view, the stresses which produce critical strains of image quality are higher than those which are dangerous for birefringence phenomenon. However, it must be taken into account the fact that the sorts of glass have different optical stress coefficients falling in a wide range of values, the ratio ends of the range is around 6 ($k=0.7\cdot10^{-6}mm^2/N\ldots4.2\cdot10^{-6}mm^2/N$), so that each application requires a separate study. Using of high k optical glass can bring birefringence at a higher rank of importance to surface deformation. Clearly, however, the effect of mechanical stress on the diopters' form should be considered for each particular application so that it can accurately prescribe contact pressure, respectively admissible clamping force.

3. CONCLUSIONS

- ≡ The performed analysis highlights a particular principle aspect, characteristic to optical components namely that strainss are more important than stresses, in terms of image quality influence.
- ≡ Optical systems with aspheric diopter have lower quality characteristics than those determined by design. The analysis of the doublet with distorted surfaces in the three studied loading cases, showed the limited loss of diffraction on the entire aperture of the system. Initial parameters of image quality were kept on 85%, 70% and 65% of the object field, to p = 2 MPa, 5 MPa, respectively 10Mpa. From a practical point of view, it might be recommend limiting the contact pressure to minimum value p = 2 MPa.
- ≡ It can be said that the optical parts mount assembly by fixing them with a threaded ring, leads to a triaxial state of stress and strain lens. Volume stressing induce birefringence phenomenon and hence an additional optical path difference of the emerging wavefront.

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