Spherical surface control by Background Oriented Schlieren method

M M Nyein
V.A. Fabrikant Physics Department, National Research University "Moscow Power Engineering Institute", Krasnokazarmennaya 14, Moscow, 111250 Russia
E-mail: myomyintnyein49@gmail.com

Abstract. The technique of automated quality spherical surfaces control using the background oriented schlieren method was presented. The results of theoretical refractive index gradient modelling for spherical lens were presented. The experimental results of spherical lenses quality diagnostics were shown.

1. Introduction
The quality of the manufactured optical components is subject to strict control [1-3]. Various purity classes are introduced for each type of optical details. Accordingly, a control system is needed either during the production process or at the acceptance stage. The dimensions and number of permissible defects on the surface and in the material of any optical component are usually known. Currently proposed methods are time consuming or require sophisticated special equipment.

The principle of the background oriented schlieren method was proposed in 1999. It allows visualizing the gradient of the investigated object refractive index [4-6]. Any defect on the surface or inside the optical part will be appearing by a change in the optical path of the radiation passing through it. Disturbance of the medium optical homogeneity is expressed in the difference of refractive index n in its volume. Often optical inhomogeneities in media are defects in the structure of a substance or the incorporation of one substance into another, which can be expressed by the presence of a refractive index gradient. Another common defect in optical details is scratches and chips, in the presence of which the optical path of the propagating light changes and a shift in the points of the background screen is also observed. For spherical surfaces and lenses, there may be disturbances in sphericity and a displacement of the center from a given one.

Accordingly, the background oriented schlieren method allows remotely diagnose the presence of defects in optical components at the stage of their production or acceptance. The use of the developed complex will significantly reduce the number of manufactured optical parts with various defects.

For the correct interpretation of experimentally obtained pictures, it is necessary to simulate the pictures of the background oriented schlieren method with all defects kinds and create a database of possible images from them [7, 8].

2. Modeling the effect of lens-like heterogenity
A plane-convex lens with know geometric parameters (curvature radius and thickness) and refractive index n is considered as a model of a constant refractive index gradient.
The beam passage through a flat-convex lens is shown in figure 1. The beam falls parallel to the optical axis at a distance $h$ from the lens center and enters the lens spherical surface. The angle of the beam incidence can be calculated by the following formula:

$$\alpha = 2 \cdot \arctg \left( \frac{-r \pm \sqrt{r^2 + 3}}{h} \right)$$

Figure 1. Screen imaging through a plano-convex lens.

In terms of geometric optics, it is possible to calculate the image displacement of the background pattern points located at a distance $s$ from the lens caused by this lens:

$$\Delta u = M\Delta dtg \left[ 2 \arctg \left( \frac{-r \pm \sqrt{r^2 + 3}}{h} \right) - \arcsin \left( \frac{1}{n} \sin \left( 2 \arctg \left( \frac{-r \pm \sqrt{r^2 + 3}}{h} \right) \right) \right) \right] + stg\gamma.$$
3. The results of experimental studies

Experimental studies of spherical lenses set with various defects were carried out to further verify the operability of the proposed method for diagnosing defects in optical details. Image registration is carried out at different distances from the camcorder to the background screen using optical and digital zoom. After that, a couple of images with the best quality were selected.

Figures 3-5 show the results of registering a background screen image with positive lenses and their processing [9]. The vectors show the direction of the refractive index gradient. Their absolute length is proportional to its value. It can be seen from the processing result that figure 3 shows a study of a good quality lens. Figure 4 shows a shift in the center of sphericity from the lens geometric center. Figure 5 visualizes the stresses of the lens material near the frame, however, the central part of the lens has no defects.
4. Conclusion
The possibility of defects visualization and quantitative characteristics of optical spherical elements quality using the background oriented schlieren method has been shown experimentally and using computer modeling. Also, during the research it was revealed that the detection of various types of defects is affected by the experimental setup parameters and window cross-correlation processing. Using the presented method of contactless diagnostics, it is possible to implement an automated complex for controlling the optical parts quality.

References
[1] Russian State Standards 28869–90 Optical materials. Methods of measuring the refractive index. (Moscow: Standartinform Publ.) (In Russian)
[2] Russian State Standards 11200–75 Objectives and tubes of microscopes. The connecting sizes. (Moscow: Standartinform Publ.) (In Russian)
[3] Russian State Standards 11141–84 Optical details. Surface cleanliness classes. Control methods. (Moscow: Standartinform Publ.) (In Russian)

[4] Meier G E A 2002 Computerized background-oriented schlieren Experiments in Fluids 33 181-7

[5] Skornyakova N M 2009 Application of the shadow background method Optical methods for the study of flows: proceedings of X Int. scientific and technical conferences (Moscow: Publishing House of MPEI)

[6] Venkatakrishnan L and Meier G E A 2004 Density measurements using the background oriented schlieren technique Exp. Fluids 37 237-47

[7] Sharma A, Kumar D V and Ghatak A K 1982 Tracing rays through graded–index media: a new method Appl. Opt. 21 984-7

[8] Doric S 1990 Ray tracing through gradient-index media: recent improvements Appl. Opt. 29 4026-9

[9] Raffel M, Willert C, Wereley S and Kompenhans Ju 2007 Particle Image Velocimetry, 2nd edn. (Berlin: Springer)