*Ewa Mróz, Romuald Pawluczyk and Maksymilian Pluta**

A Method for Coherent Optical Noise Elimination in Optical Systems with Laser Illumination**

A method for coherent optical noise elimination in optical systems with laser illumination is described. To eliminate the noise rotating glass blocks in the form of a right prism are used. Application possibilities of this method in the two-beam laser interference systems with straight fringes are shown. Experimental results obtained by using this method in a biological microscope, double-refracting interference microscope, multiple-beam micro-interferometer and Twyman–Green interferometer with laser illumination are given. A comparison was also made between the results obtained with the rotating block and with the rotating ground glass.

I. Introduction

Application of lasers in optical systems is often limited by a coherent optical noise. Diffraction and interference patterns are generated by optical system imperfections (discrete scratches, bubbles, dust particles, inhomogenities in glass and glue, as well as reflections from the air-glass interfaces) when a spatially coherent light is used. These noisy patterns often completely obliterate the subject of interest. Elimination of this disturbing coherent noise is a serious problem.

Several authors have described methods of improving the image quality in coherent illuminated systems. Kirkpatrick and El-Sum [3] have partially destroyed the coherence between the light source and the object by using a light source continuously rotating about the optical axis of the system. Experiments with optical systems, in which all the optical components were rotating about the optical axis, have been also performed by some authors. Next, the method of diffuse illumination has been used [6, 7]. A light scattering screen, placed in the path of a laser beam, suppresses the coherent noise, but it causes a granular structure or speckle to appear at any plane downstream from the diffuser. Considine [2] has used a weak milk-water solution as a diffuser. This is a fine structure and a time-varying diffuser, as milk particles undergo Brownian motion. It allows to obtain images the structure of which is comparable to that obtained with incoherent illumination. The speckle pattern, as a characteristic phenomenon for coherently illuminated systems, may be removed by using rotating diffusers, for instance a ground glass screen, which is rotating about the axis parallel to the optical axis of the system. When the speed of the rotation is such that during a time equal to the persistence time of vision (or photographic exposure time) the speckles are moved further than their periodic spacing, uniform illumination is obtained. Bowman [1] has described experiments with a rotating polished glass disc, one surface of which was smeared with a thin layer of translucent silicone grease acting as a scattering screen. In general, all scattering screens cause high losses in light intensity across the object plane. Upatnieks [9] has obtained a considerable improvement of the image quality in optical systems with laser illumination by using a pure phase diffuser placed close to the object. This method is applicable only to two-dimensional objects, moreover only the diffraction patterns scattered downstream from the object plane are eliminated. Then, another method has been suggested by Leith and Upatnieks [4]. The image quality may be improved by passing the coherent beam through a pseudo-random diffuser formed, for instance, by a contact print-

* Address: Centralne Laboratorium Optyki, Warszawa ul. Kamionkowska 18, Poland.

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ing a pair of crossed Ronchi gratings on the photographic plate and then by bleanching this plate. Thomas [8] has worked out a technique for the time averaging of the coherent noise without reducing the spatial coherence of illumination. The optical system in his experiments was perturbed in such a manner that the noise at the output of the system varied with time, while the image of interest remaind stationary. A rotating flat glass plate tilted slightly out of the plane perpendicular to the optical axis of the system was used as an averaging element. When the rotating plate is placed in an illumination beam, diffraction patterns due to imperfections of optical elements move, while the image of the object of interest is fixed. The output detector (eye or photographic film) averages the fluctuation intensity of the noise patterns. This method, however, does not work with plane waves. Bowman [1] has used a rotating, optically transparent disc in the form of a thin wedge spun about the axis parallel to the optical axis of the system. This technique, in contrast to Thomas' method, may be used for plane waves. In this paper a new method for coherent noise averaging is presented. The method is a further modification of the Thomas' and Bowman's techniques.

II. Principle of the method

The basic novelty in our method is a glass multi-sided block, in the form of a right angle prism, used as a coherent noise averaging element. The block rotates about the axis perpendicular to the optical axis of the system.

The operation of this element for a convergent illumination beam, is explained in Fig. 1. The laser beam LB expanded by the lens L_1 falls on the four-wall glass block B, which is rotated about the axis O perpendicular to the drawing plane. The block causes displacements of the illumination beam on the observation plane P. When the block rotates, the angle of incidence on the lens L_2 varies and is determined by the momental position of the block B. As a result of this, the diffraction patterns N' and N'' produced by an imperfection N in the lens L_2 move in the observation plane P. N' and N'' are, of course, in two different places for two different positions of the block B. The eye (or photographic plate) integrates the time-varying illumination in the observation plane and thus averages much of the diffraction noise.

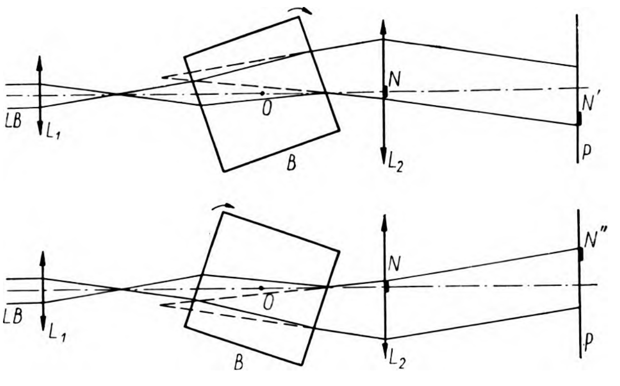


Fig. 1. Operation of a transparent four-wall block in a convergence beam

An experimental device for the suppresion of the coherent noise in optical systems with laser illumination is shown in Fig. 2. Two six-wall blocks B_1 and B_2 are placed in the laser beam LB downstream to the focus of the lens L in front of an optical system OS. The blocks rotate about the axes O_1 and O_2 perpendicular to the optical axis of the system OS. Each block causes a linear motion of the illumination beam. If the blocks rotate with

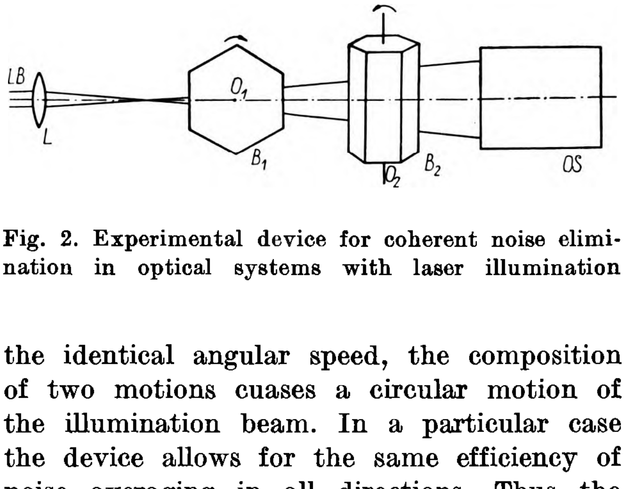


Fig. 2. Experimental device for coherent noise elimination in optical systems with laser illumination

the identical angular speed, the composition of two motions cuases a circular motion of the illumination beam. In a particular case the device allows for the same efficiency of noise averaging in all directions. Thus the noise such as, for instance, diffraction patterns produced by two perpendicular scratches on the surface of a lens, may be effectively eliminated. For special applications the blocks B_1 and B_2 may be adjusted so that axes O_1 and O_2 are not perpendicular and rotation speeds of the blocks are different.

III. Applications

The described device can be applied in different optical systems with laser illumination. We have performed several experiments to study the operation of this device in different laser systems, among others, in biological and interference microscopes with laser illumination. We have compared the results obtained with our averaging device and with a rotating ground glass.

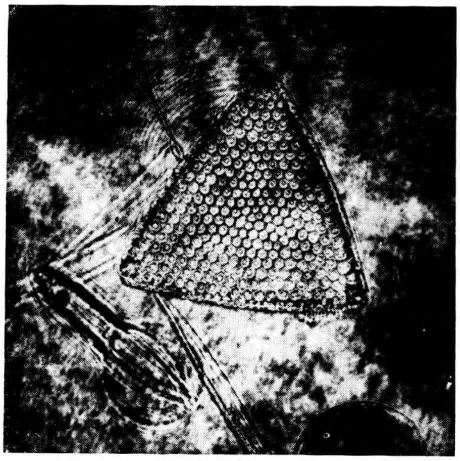
A) Biological microscope with laser illumination

A microscopic image of a biologic specimen illuminated by a laser light is shown in Fig. 3. It can be seen that the image is strongly disturbed by a coherent noise, as shown in Fig. 3a. Fig. 3b and 3c present the same image obtained with one and two rotating blocks, respectively. The image quality obtained with the two--blocks averaging device is better than that obtained with one rotating block. By applying the averaging device a considerable improvement of this image quality may be obtained.

The comparison images obtained in the microscope with a rotating ground glass and a rotating block are presented in Fig. 4a and 4b, respectively. In Fig. 4a some blurrings which reduce the image contrast are observed. These effects are not seen in Fig. 4b with averaging device. The above results indicate that a rotating block is better than a rotating ground glass.

B) Laser interference systems

Lasers, as instruments producing high intensity and spatially coherent light, are excellent light sources for interferometry. However, coherent noise, sometimes, stands in the way of the effective application of these sources. We have performed several experiments aimed at the noise eliminating by using different methods, among others, a rotating ground glass. We can conclude, that in interference systems the best results are given by the averaging method. In interference systems with straight fringes one-directional averaging is required. It means that one rotating block is used, which causes, that the illumination beam moves in one direction only. Moreover, the adjusting of the rotating block is required to assure, that the direction of the motion be parallel to the direction of the interference fringes.



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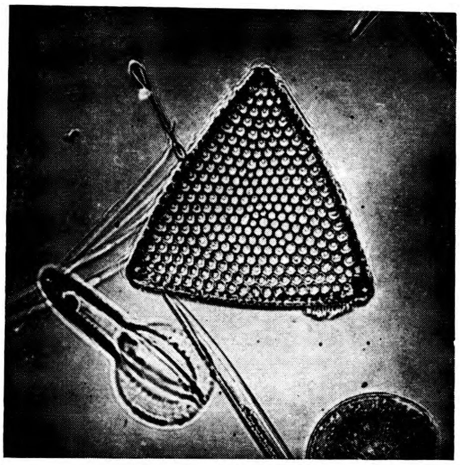

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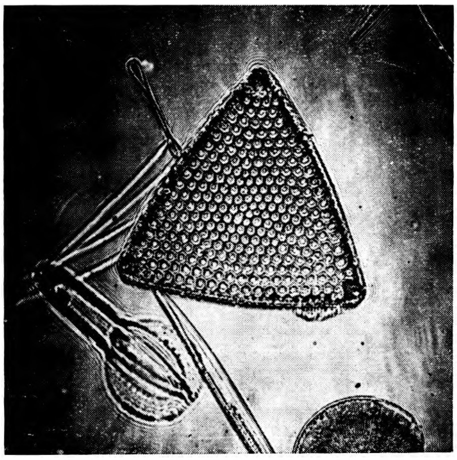

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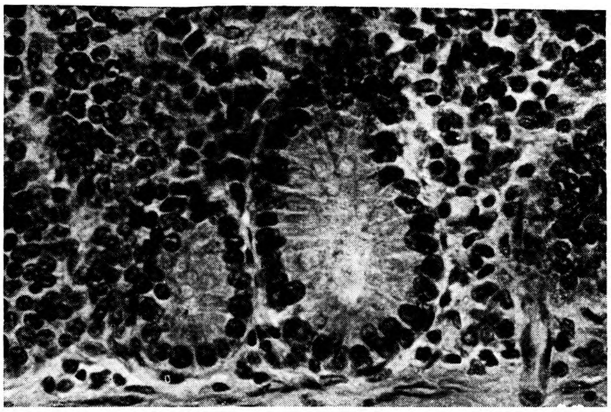
Fig. 3. Images of diatoms in a biological microscope with laser illumination: a) without noise elimination, b) with one rotating block, c) with two rotating blocks as shown in Fig. 2



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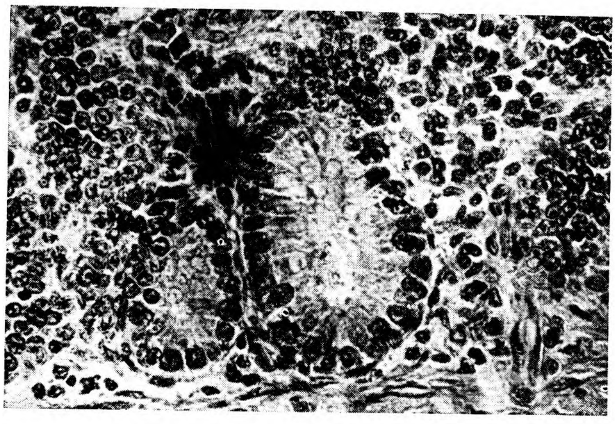

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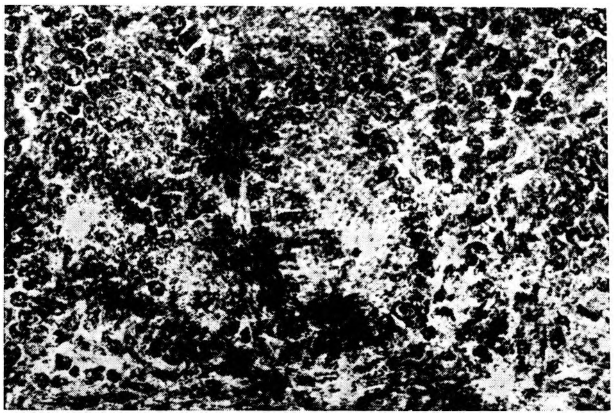
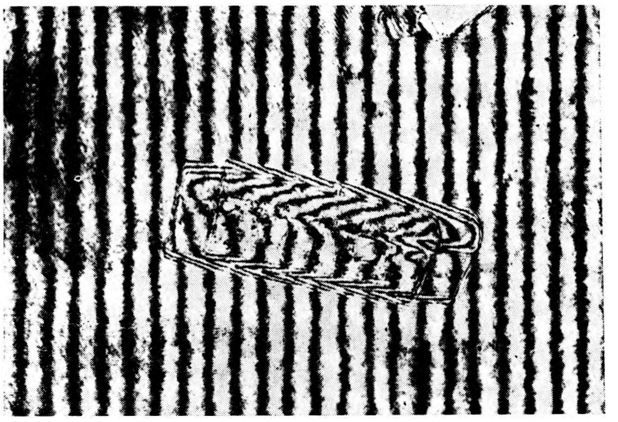


c)

Fig. 4. Images of a mamalian small intestine in a biological microscope with laser illumination: a) with a rotating ground glass, b) with a rotating block, c) without noise elimination

First of all we have worked on coherent noise elimination in a double-refracting interference microscope [5] with laser illumination. Application of laser light in this microscope allows to improve the precision of microscopic measurements. An inacurracy of measurements caused by differences of dispersion in the examined object and its environment may be eliminated by using monochromatic laser light together with coherent noise elimination.

The results of coherent noise elimination in the above mentioned microscope are presented in Fig. 5. The image of a birefringence crystal in the interference fringe field without noise elimination is shown in Fig. 5a, and the same



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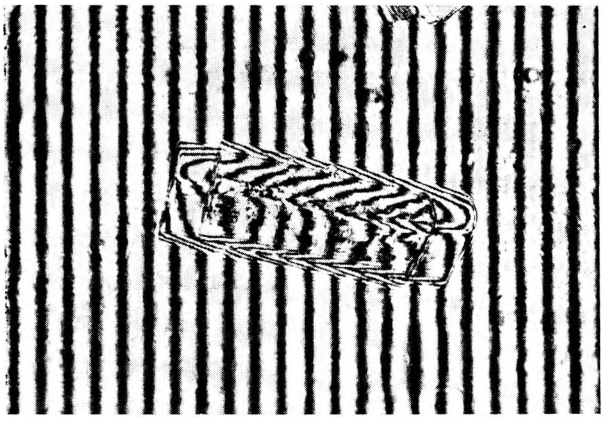

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Fig. 5. Images of a birefringence crystal in a double-refracting interference microscope with laser illumination, interference fringe field method: a) without noise elimination, b) with a rotating block

image with the rotating block is presented in Fig. 5b. It can be seen that much of the noise is eliminated by applying the rotating block. Small size interference rings in Fig. 5b are caused by dust particles on the object slide. These rings are not eliminated because, their sources are near to the object plane. In Fig. 6 the images of a biological specimen in the uniform interference field with large image duplication are shown. Fig. 6a presents the image without noise elimination while Fig. 6b that obtained with the rotating block. In this case the adjusting of the rotating block was the same as for the interference fringe field.

We have also performed experiments on noise elimination in such interference systems as the Twyman–Green interferometer with laser illumination and the laser multiple-beam microinterferometer. Figs 7a and 7b present the image of a glass plate in the Twyman–Green interferometer without noise elimination and with a rotating block, respectively. In Fig. 8 the multiple-beam interference images of dielectric stripes evaporated onto a glass plate are shown. The image 8a corresponds to the ordinary laser illumination without noise elimination, while the image 8b to the illumination with a rotating block. The optical thickness of these stripes is 0.19 λ for laser light 632.8 nm. The microinterferometer works in reflected light. The wavy shape of the interference fringes is caused by overlaping the multiple-beam interference image and another image formed by interference of light reflected within the substrate glass plate. This plate does not have ideal plane- parallel surfaces.

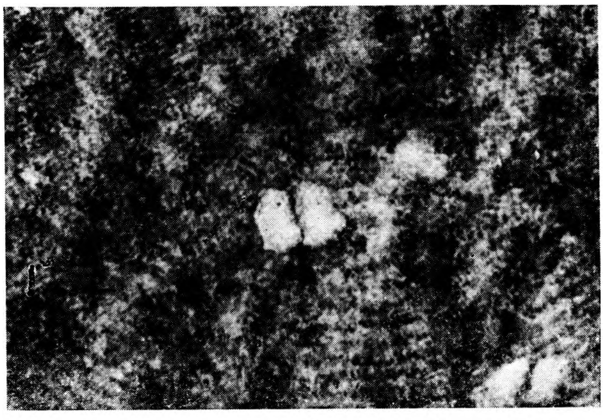

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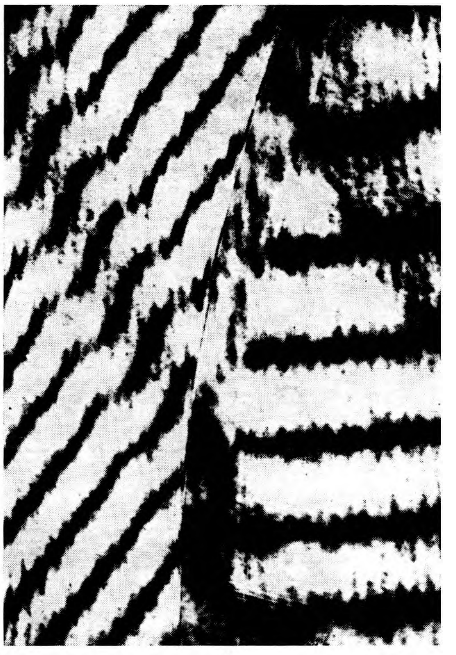
Fig. 6. Images of human epithelial cells in a double-refracting interference microscope with laser illumination, uniform field interference method with large image duplication: a) without noise elimination, b) with a rotating block



a)

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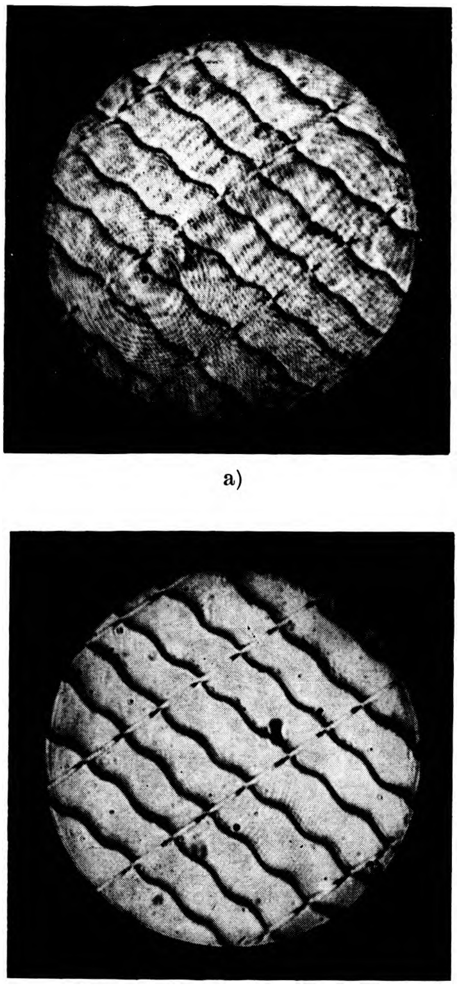
Fig. 7. Images of a glass plate in the Twyman-Green interferometer with laser illumination: a) without noise elimination, b) with a rotating block

From these experiments we conclude that the described method of coherent noise elimination can be applied in laser interference systems



a)

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Fig. 8. Images of dielectric stripes on glass slide in a laser multiple-beam microinterferometer: a) without noise elimination, b) with a rotating block

with a fringe or uniform interference field. This method effectively eliminates coherent noise and does not disturb interference patterns of interest.

IV. Conclusions

A method for the time averaging coherent noise in the optical system with laser illumination is described. In this method one or two rotating blocks are applied. The blocks are adjusted in a different manner, according to the desired applications. In general, the blocks have the form of a multiple-wall prism and are made of glass or other transparent materials. Reflection blocks can also be used, however, they have inferior properties as compared to the transparent ones. Blocks with an even and odd number of side walls, when properly adjusted to the optical axis of the system, act as rotating plane slides or rotating wedges. They can be applied in parallel, convergence or divergence beams. The averaging devices with rotating blocks have simple construction and higher effectiveness of noise elimination as compared to the rotating plane slides and wedges with the same speed of rotation. The described method can be used in both the two-beam and multiple-beam interference systems with straight fringes. In this case one-directional averaging is applied, and the rotating block is positioned so that the illumination beam moves in the direction parallel to the fringes. The results obtained with averaging devices in a biological microscope, double-refracting interference microscope, Twyman–Green interferometer and multiple-beam microinterferometer are presented. A comparison of the results obtained with the rotating blocks and those received with a rotating ground glass indicates that the proposed averaging method is better than the rotating ground glass method. The more so that the averaging method does not disturb the images, which is observed with a rotating ground glass. To obtain high image quality in interference systems it is required that all side walls of the block be parallel to its axis of rotation.

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Méthode d'élimination des bruits optiques cohérents dans les systêmes optiques à eclairage de laser

Dans le travail on présente la méthode d'élimination des bruits optiques cohérents dans les systèmes optiques à éclairage de laser. On y a utilisé des prismes droits de verre tournants. On a montré les applications possibles de cette méthode aux systèmes intreférentiels de laser à deux faisceaux et à faisceaux multiples avec les franges d'interférences rectilignes. Les résultats des expériences illustrant la méthode sont donnés. On a expérimenté en utilisant les dispositifs suivants (tous à éclairage de laser): le microscope biologique, le microscope interférentiel à polarisation avec le prisme de Wollaston, le mictrointerféromètre à rayons multiples et l'interféromètre de Twyman-Green.

On a comparé les deux méthodes d'élimination des bruits cohérents — la méthode des prismes droits de verre tournants et celle de plaque de verre dépoli tournante.

Метод элиминирования оптических когерентных шумов в оптических системах с лазерным освещением

В работе описывается метод элиминирования оптических когереитных шумов в оптических системах с лазерным освещением, использующий вращающнеся стеклянные бруски, имеющие форму прямой призмы. Представлена возможность применения этого метода в двулучевых и многолучевых лазерных интерференционных системах работающих в однородном и поласатом интерференционных полях. Приводятся результаты исследований применения этого метода в биологическом микроскопе с лазерным освещеием, в интерференционно-поляризационном микроскопе с призмой Уоллостона с двойным лучепреломлением, в лазерном многолучевом микроинтерферометре и в интерферометре Туаймана-Грина с лазерным освещением.

Сравниваются два метода элиминирования оптических когерентных шумов — метод вращающегося стеклянного бруска и вращающегося матового стекла.

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