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AN INTERFERENTIAL ~~INTERFERENCE~~ INVESTIGATING ~~STUDYING~~ METHOD FOR ~~STUDYING~~ RELATION THE ~~CONNECTION~~ BETWEEN THE STRUCTURE OF WAVE SURFACES AND THE STRUCTURE OF ~~THE~~ ENERGY-DISPERSION SPOTS

A. P. Moroz

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1. Theory of the Method

Let a certain plane intersect the ~~conjuction~~ juncture of the normal to a ~~the~~ wave surfaces (rays) of ~~which have an~~ arbitrary structure; and let us consider ~~ex-amine the~~ point, or spot, of ~~the~~ energy dispersion, which is represented in this plane as a monochromatic point emitter. The structure of ~~the energy~~ dispersion ~~points~~ spots depends upon the structure of the ~~wave surface and on~~ its ~~restriction~~ limits. Within the limits of the region ~~area~~ in which the plane cuts the ~~conjunction~~ juncture of the normal to the wave surfaces, a macrostructure and a ~~the macro-~~ micro-structure of the energy-dispersion ~~points~~ spot exist. The macrostructure is determined by the ~~location~~ position of each point of intersection of the plane with the normal to the ~~relative~~ wave surface relative to the section of the normal containing centers of curvature of various normal cross-sections ~~which~~ of the correspond~~ing to the~~ element of the wave surface and relative to the length of this section. The macrostructure basically forms the energy-dispersion ~~points~~ spot and particularly determines the ~~location~~ position and characteristics of ~~the~~ its brightest ~~of its~~ elements. Imposed on the macrostructure the periodic microstructure appears as ~~the~~ a result of ~~an~~ interference of disturbances, occurring in every ~~examined~~ point of the dispersion spot under study, from ~~all~~ the entire wave surfaces. Calculation, ~~with Gyuygens-Frenells~~ by the Huygens-Fresnel principle, of the distrubution ~~of~~ energy in ~~the~~ a dispersion spots for a point monochromatic emitter ~~can and~~ can even not give a picture of the macro-structure of ~~the~~ an energy-dispersion spots ~~found in testing~~ as observed in tests, since, in the case of a point emitter, ~~maximum energies~~ energy maxima in corresponding places

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of the spots can not generally ~~speaking~~ be separated ~~according to~~ by brightness as compared with other diffraction ~~maximums~~ maxima. However, ~~by~~ pari passu with ~~the degree of~~ increases in the ~~disc~~ diameter ~~growth~~ of the disc representing the emitter, a dispersion-spot's diffraction contours ~~of the dispersion spots~~ coinciding with its macro-structure picture, ~~according to the dimensions of the diameter of the disc,~~ must remain sharply outlined ~~during the period that~~ while other diffraction contours of a ~~the~~ dispersion spots are fading. ~~An examination~~ consideration of the geometry of wave surfaces permits one to localize ~~ation of~~ the ~~picture of the~~ macrostructure of ~~the~~ an energy-dispersion spots and ~~to~~ describe ~~discription of~~ its characteristics.

A. CLASSIFICATION OF THE ELEMENTS ~~OF THE~~ MACROSTRUCTURE OF ~~THE~~ AN ENERGY-DISPERSION SPOTS

There exist three specific types of energy concentration in a dispersion-spot's ~~the~~ elements ~~of dispersion points which form their~~ that make up the spot's macrostructure. These are: ~~the~~ focal nucleus, elements of the picture ~~of the~~ focal lines, and diffusion elements. The elements of a dispersion spots that belong ~~ing~~ to a ~~the~~ given type of concentration, possess ~~have~~ characteristic properties which determine their role in ~~the~~ image formation ~~of the picture~~.

It is convenient ~~easy~~ to consider ~~examine~~ wave surfaces composed ~~which are made up~~ of elements. The **normal** to each of the elements coincides with the ray emanating from the corresponding point of the 'discharge focus' of the **aberration** system. Let us consider ~~examine~~ any arbitrary element of a wave surface and let a ~~the~~ normal be erected ~~constructed to~~ on it. The of curvature radii of various normal cross-sections of this element can be different (astigmatic element) or ~~can be~~ alike (a astigmatic element).

The of curvature centers of various normal cross-sections of a ~~the~~ element ~~of the~~ wave-surface form a of the normal segments, limited by the centers of curvature ~~restricting main~~ of pairs of its main cross-sections ~~by curvature centers~~ (astigmatic difference).

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Each point ~~of~~ in the segment of the curvature centers ~~segments~~ correspond to a pair of normal cross-sections of ~~the~~ a wave-surface element whose curvature centers are ~~found~~ located in this point. The angle between these normal cross-sections ~~changes~~ varies ~~during transition at the passage~~ from point to point of the ~~curvature center~~ segment containing the centers of curvature. It is equal to zero ~~in~~ at the point representing the curvature center of the main cross-section of ~~the~~ a wave-surface element, and consequently, in the case of ~~the~~ an astigmatic wave-surface element, it becomes zero twice.

Wave-surface elements, in which ~~the~~ a system converts ~~the specific~~ a spherical wave ~~falling on~~ incident upon it, dan be distinguished thus:

1) In the sense of the length of the normal segment of a having of curvature centers of the normal cross-section of the wave surface element. The wave surface can in particular have elements for which ~~whose~~ this length becomes zero (anastigmatic elements ~~of~~ wave-surface);

2) in the sense of the ~~location~~ position of this segment of ~~the~~ centers of curvature ~~center~~ on the normal;

3) In the sense of the orientation of a pair of ~~main~~ mutually-orthogonal main cross-sections of ~~the~~ a wave-surface element.

The geometric ~~place~~ locus of the curvature centers of the main cross-sections of the wave-surface elements forms the caustic (focal) surface.

Each astigmatic wave-surface element forms two points of this surface, ~~moving~~ shifted (points) one relative to another along the corresponding normal. Each anastigmatic wave-surface element forms one point of the caustic surface -- its ~~point~~ cusp. The wave surface can contain anastigmatic elements having a ~~general~~ common center of curvature ~~center~~ which forms, consequently, a common cusp ~~general point~~ of the caustic surface. Curvature centers of ~~various~~ different anastigmatic wave-surface elements ~~do~~ need not ~~have to~~ coincide. In this case they form various ~~points~~ cusps of the caustic surface which can appear ~~scattered~~ disposed in space on the corresponding normals in any way, and in particular, in one focusing plane.

The intersection of each of the normals with the focusing plane deter-

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mines a certain point of the dispersion spot. Each point of the dispersion spot can appear variously distributed along the normal, to which it belongs, relative to the segment of the curvature centers of the corresponding wave-surface element. The length of this segment can vary for various wave-surface elements. By using these ~~characteristics~~ indices, one can classify the elements of the energy-dispersion spots ~~can be classified~~.

1. Focal Nucleus. This is an element of the dispersion spots around its point, coinciding with the centers of curvature ~~center~~ of the anastigmatic wave-surface element. The dispersion spot can contain several focal nuclei, one focal nucleus, or none.

2. Element of the focal line ~~lines~~. This is an element of the dispersion spot around its point coinciding with the centers of curvature ~~center~~ of one ~~of the~~ pairs of main cross-sections of an astigmatic wave-surface element. The picture of focal lines of an ~~the~~ energy-dispersion spots is formed in the intersection of the plane with the caustic surface. Eavh point of this picture is connected by a ray with a certain point of the discharge pupil of the system.

The focal-line element can ~~be~~ degenerate at the point where the caustic-surface 'hollow' ~~cavity~~ degenerates into the line formed in the intersection with the plane the referred-to point. For example, in the case of spherical ~~specific~~ aberration, one of the caustic-surface 'hollows' ~~cavities~~ degenerates in a straight line coinciding with the axis of the system.

3. The diffusion element of a ~~the~~ dispersion spot is formed around its point, which does not belong to the caustic surface. This is the internal diffusion element, ~~it occurs~~ when the point is located ~~found~~ within the segement of the centers of curvature ~~centers~~ of the corresponding wave-surface element; i.e. In the opposite case it is the external diffusion element. As a result of restricting on of the wave surface, the energy can be present at ~~in~~ the points ~~which do~~ not belonging ~~relate~~ to the normals to the wave surfaces. The dispersion-spot element around such points are diffusion

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diffraction ~~defractionary~~ elements.

Normals to various wave-surface elements can be intersected and, consequently, can be superimposed ~~on~~ diffusion-spot elements of different ~~various~~ or similar types.

If they are shifted (along the) ~~the~~ normals to ~~the~~ an anastigmatic wave-surface element ~~are moved~~, then the corresponding dispersion-spot element ~~is~~ in various planes ~~gradually~~ becomes in succession ~~an~~ external diffusion -- focal nucleus -- external diffusion ~~element~~. In the case of the astigmatic wave-surface element, the diffusion-spot element ~~gradually~~ becomes successively ~~an~~ external diffusion -- focal-line element -- internal diffusion -- focal-line element -- external diffusion ~~element~~.

The energy-dispersions spot can contain elements of all three types of concentration or only certain of them, according ~~which correspond~~ to the wave-surface structure.

SPACE

B. Wave Surfaces Aberration, Isophase lines on the Pupil and classification of the discharge pupil Elements of an Optical System (CAPS!)

SPACE

Let us study the properties of a ~~the~~ discharge pupil element of an optical system ~~in the vicinity of~~ its point (O) from which a ray arrives at ~~enters~~ a given point (Ω) of the dispersion spot.

Let a spherical ~~specific~~ light wave, whose center coincides with the bright spot, or focus, encounter an optical system and be ~~is~~ converted by it.

We can compare the real ~~actual~~ wave surface, emanating from the system, with spheres whose centers coincide with various points (Ω) of the dispersion spot in the given focus plane. The physical sense of such a comparison is included in the fact that the real ~~actual~~ wave surface is compared with wave surfaces ~~which~~ existing in the case of an ideal system whose centers of curvature ~~centers~~ would coincide with the studied points (Ω) of the dispersion spot. In the general case of an ~~the~~ aberration ~~of the~~ system there are ~~is~~ no ~~based~~ s apriori for ~~on~~ giving preference to ~~a comparison with~~ some ~~kind of~~ sphere of comparison.

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About any point (Ω) of ~~the~~ a dispersion spot, ~~there~~ one can ~~be~~ constructed, as around the center of ~~the~~ a sphere of a certain radius r, a comparison ~~with a~~ sphere, tangent to the wave surface at point (0) whose normal contains this point (Ω). ~~A~~ Deviations of the wave surface from the comparison sphere ~~is~~ are read along the radius of the latter and ~~is a~~ represent values of the wave aberration I_Ω of the system for the point (Ω). The intersection of each radius of ~~compared~~ a comparison sphere with the discharge pupil forms its point for which the wave aberration is determined along this radius. Thus, ~~there~~ one can ~~be~~ constructed, ~~in~~ as a functions of the coordinates of the points of the discharge pupil (or some other plane) of ~~the~~ a system, a surface of ~~a~~ wave aberration I_Ω, for the studied point (Ω) of the energy-dispersion spot, which characterizes the deviations of the ~~actual~~ real wave surface from the ~~specific~~ spherical wave surface whose center coincides with the studied point (Ω). The surface of the wave aberration corresponds to a ~~set~~ family of isophase (isoaberrational) lines on the discharge pupil of the system for the point (Ω). Each such line ~~joins~~ unites the pupil point with a ~~uniform~~ similar value of the wave aberration for ~~the~~ point (Ω). Let ~~the~~ an element (0) of the wave surface radiate from ~~the~~ an arbitrary element (0) of the discharge pupil in the system. The point (Ω) of ~~the~~ intersection of a) the normal to the element (0) of the wave surface with b) a certain plane represents the studied point of the energy-dispersion spot in this plane.

Let the center of the compared sphere, tangent to the wave surface at the point (0), be located in this point (Ω). The compared sphere ~~imparts to~~ assigns for the point (Ω) a surface of wave aberration I_Ω and a ~~set~~ family of isophase lines on the pupil. Element (0) of the surface ~~of the~~ wave-aberration corresponds to the element (0) of the wave surface.

Many comparison spheres can ~~be~~ one constructed which are tangent to the wave surface at the point (0) and whose curvature centers are ~~located~~ disposed ~~in~~ at various points (Ω) of the ~~examined~~ normal under consideration.

What are the properties of the element (0) of the ~~surface of~~ wave-

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aberration surface and isophase lines in ~~the vicinity~~ near of ~~the~~ an arbitrary point (O) of the discharge pupil, a ray of ~~the pupil~~ which point contains ~~the~~ a point (Ω) ~~The pupil is combined~~ coinciding with the center of the compar~~ed~~ison sphere ~~due to~~ because of the ~~characteristics~~ properties of the element (O) of the wave surface and with the position ~~location~~ of the point (Ω) on the normal.

Let us ~~examine~~ consider the plane cross-section of the pupil element (O), ~~which is~~ (section) represented as the path of intersection with the pupil plane of a certain normal cross-section of the element (O) of the wave surface. Let the studied point (Ω), ~~which is joined~~ coincident with the center of the compar~~ed~~ison sphere, be shifted along the normal ~~to a distance~~ (by a magnitude Δ) from the curvature center of the examined normal cross-section of the wave surface element (O).

With the aid of a geometric construction it is easy to see that, near in the vicinity of the point (O) of the pupil plane (or any other plane), the wave aberration $I_\Omega = I_\Omega(\sigma)$ in the examined cross-section of element (O) of the pupil is described by the following expression:

$$I_\Omega(\sigma)\Big|_{\substack{\sigma\to 0\\ \Delta \ll 1}} = \frac{\Delta}{2r^2}\sigma^2\cos^2\gamma \qquad (1)$$

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where σ is the linear distance in the examined cross-section of the pupil element (O); r is the radius of the compar~~ed~~ison sphere whose center of curvature ~~center~~ coincides with the point (Ω) and which is tangent to the wave surface at the point (O); γ (gamma) is the angle between the straight lines ~~which~~ forming the plane of the normal cross-section in the plane ~~which is~~ tangent to the wave surface at the point (O) and in the pupil plane; ρ is the radius of curvature of the examined cross-section of the wave-surface element (O). It follows from formula (1) that when $\sigma = 0$, that is, ~~in the~~ at point (O) of the pupil, in any cross-section (i.e. ~~with~~ for any value of Δ) ~~value of Δ there takes place~~ we have the following relations:

$$I'_\Omega(\sigma)\Big|_{\sigma=0} = 0 \quad \text{and} \quad I''(\sigma)\Big|_{\sigma=0} = \frac{\Delta}{r^2}\cos^2\gamma \qquad (2)$$

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It is clear from formulas (2) that element (0) of the surface of the wave aberration is always an extremum for any point (Ω) belonging to the normal to the wave surface at point (0). The sign of this extremum in any cross-section of the element (0) of the 'pupil' is determined by the sign of Δ for the corresponding normal ~~of the~~ cross-section of the wave-surface element (0). In cross-sections of the 'pupil' element (0) corresponding to the normal cross-sections of the wave-surface element (0) whose (cross-sections) of curvature centers coincide with the point (Ω), (i.e. for which $\Delta = 0$) there is an inflexion point; we have simultaneously the relations:

$$l'(\sigma)\Big|_{\sigma=0} = l''(\sigma)\Big|_{\sigma=0} = 0. \qquad (2') \quad p307$$

Let us examine the properties of the isophasic (iso-aberration) lines ~~in the vicinity of the~~ near point (0) in the plane tangent to the wave surface at this point. These isophasic lines describe the element (0) of the surface at this point. These isophasic lines describe the element (0) of the surface of the wave aberration. The projection of such an isophasic lines from the point (Ω) on to a discharge 'pupil' plane represents ~~the~~ an isophasic lines ~~in the vicinity of~~ near the 'pupil' point (0). We will designate by σ_0 the linear distances from the point (0) in the tangent plane in the cross-section, which corresponds to the examined cross-section of the 'pupil' element (0). The wave aberration, expressed ~~by~~ in terms of σ_0, is:

$$l_\Omega(\sigma_0)\Big|_{\substack{\sigma\to 0\\ \frac{\Delta}{\rho}\ll 1}} = \frac{\Delta}{2r^2}\sigma_0^2. \qquad (3) \quad p307$$

From the general expression for the curvature radius of we can see that the of curvature Radius R_Ω at the point (0) of the wave-aberration surface in the ~~examined~~ cross-section considered is equal to:

$$R_\Omega = \frac{[1+(l'_\Omega)^2]^{3/2}}{l''_\Omega} \doteq \frac{r^2}{\Delta} \qquad (4) \quad p307$$

Allowing for (3), we can rewritten formula (4) thus:

$$\frac{\sigma_0^2}{2l_\Omega(\sigma_0)}\Big|_{\sigma_0\to 0} = R_\Omega. \qquad (5)$$

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A Dupin indicatrix can be constructed for the point (0) of the wave-aberration surface. To do this, in the tangential plane to the surface at the point (0) it is necessary to plot from the point (0), along each tangent, a segment, a distance equal to the square root of the absolute size of the curvature radius of corresponding to the normal cross-section of the wave-aberration surface element (0); i.e. the dimension $A = \sqrt{|R_\Omega|}$. Dupin's indicatrix is the central curve of the second order with center at the point (0). On the other hand, from formula (5) we get

$$\sigma_0 = \sqrt{2\, l_\Omega(\sigma_0)} \cdot \sqrt{|R_\Omega|} \qquad (6) \qquad p.307$$

If $l_\Omega(\sigma_0) =$ const. is given some kind of values for various normal cross-sections of the wave-aberration surface element (0), then the values of σ_0 which is obtained from (6), plotted along the corresponding tangents to this element, form geometrical group of points of similar values of wave aberration in the vicinity of the point (0); i.e. an isophase line. From (6) it is clear that the isophase live in the vicinity of the point (0) is a central curve of the second degree with center at point (0) similar to Dupin's indicatrix. It is obtained if all the radius vectors, plotted from point (0) in the tangent plane, are equal to the size of $\sqrt{|R_\Omega|}$ and whose ends form the Dupin indicatrix, changed $\sqrt{2\, l_\Omega(\sigma_0)} =$ const. times.

Let us examine what occurs with the element (0) of the wave-aberration surface and the element of the isophase lines, corresponding to the wave-surface element (0), when the center (Ω) of the comparison sphere tangent at the point (0) is moved along the normal to the mentioned wave-surface element (along the ray). At this it occupies gradually different positions (Ω) determining the dispersion-spot points in various planes of the arrangement connected with the general normal.

The wave surface can contain astigmatic and anastigmatic elements.

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Let us examine the case of the wave-surface astigmatic element of a ray.

For any ~~location~~ position of the point (Ω) on the ray, outside of its segment, containing centers of curvature ~~centers~~ of normal cross-sections of the wave-surface element (O), the point (O) of the wave-aberration surface is elliptical. The isophase line is an ellipse with center at ~~the~~ point (O) and with axes which coincide with the directions of the main cross-sections of the wave-surface element.

~~At a location~~ For positions of the point (Ω) within the mentioned ray segment, the point (O) of the wave-aberration surface is hyperbola. Isophase line is represented here as a pair of coupled hyperbolas with center at ~~the~~ point (O) and with axes oriented as in the previous case. The asymptotes of these hyperbolas represent a pair of normal cross-sections of the wave surface of the element (O), whose centers of curvature ~~centers~~ coincide with the point (Ω). The angle W_0 between the asymptotes is described by the expression

$$tg^2 \frac{W_0}{2} = -\frac{\Delta_u}{\Delta_v} \qquad (7)$$

where the deltas are the distances along the ray from the point (Ω) to the centers of curvature ~~centers~~ of the main cross-sections of the wave-surface element (O). From (7) it is clear that, ~~with a shift~~ for a displacement of the studied point of the dispersion spot along the ray within the limits of the segment of the centers of curvature ~~centers~~, the angle between the asymptotes continuously ~~uninterruptedly~~ decreases. The angle between them becomes zero when the point (Ω) coincides with the curvature center of each of the pairs of the main cross-sections of the wave-surface elements. Here the hyperbolas degenerate into straight lines which have the direction ~~which~~ of the corresponding ~~to the~~ main cross-section. The hyperbola asymptotes of them in the discharge pupil plane are ~~represented as~~ the above-mentioned projections from the point (Ω) of the asymptotes in the plane ~~which is~~ tangent to the wave-surface element (O).

The point (O) of the wave-aberration surface is parabola when

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the point (Ω) coincides with the curvature center of the main cross-section of the wave-surface element (0). Simultaneously in this cross-section $l'_{\Omega}\big|_{\sigma_0=0} = 0$ and $l''_{\Omega}\big|_{\sigma_0=0} = 0$; in the remaining main cross-section only $l'_{\Omega}\big|_{\sigma_0=0} = 0$.

On the last cross-section, there is accordingly a maximum or minimum ~~corresponding~~ of the position ~~location~~ of the point (Ω) relative to the curvature center of the remaining main cross-section. The isophase line is represented here by a pair of straight lines, parallel to the main cross-section, whose curvature center coincides with the point (Ω).

In the case of the anastigmatic wave-surface element (0), the wave-aberration surface element (0) remains an element of the rotation paraboloid of for all positions of the point (Ω) on the ray. When the point (Ω) coincides with the curvature center of the wave-surface element (0), then we have simultaneously: $l'_{\Omega}\big|_{\sigma_0=0} = 0$ and $l''_{\Omega}\big|_{\sigma_0=0} = 0$ (7') in all normal cross-sections of this element. When the point (Ω) does not coincide with the mentioned center of curvature ~~center~~, the positions of the we have $l'_{\Omega}\big|_{\sigma_0=0} = 0$ and $l''_{\Omega}\big|_{\sigma_0=0} \lesseqgtr 0$ (7'') i.e., it is a maximum or minimum depending on the ~~location~~ position of the point (Ω) on the ray relative to the curvature center. The isophase line is a circle for all positions of the point (Ω). In this case, the wave-aberration surface point is umbilical.

If the point (Ω) coincides with the curvature center, then ~~the~~ point (0) of the wave-aberration surface is focal umbilical (or simply umbilical). In the opposite case it is not focal umbilical.

Thus, ~~at the movement of~~ when the studied point (Ω) moves along the normal to the astigmatic wave-surface element (0), the point (0) of the wave-aberration surface successively becomes ~~in turn~~ elliptical -- parabolic -- hyperbolic -- parabolic -- elliptical. Simultaneously ~~At the same time~~, the appearance of the isophase line varies ~~change~~ ~~in the vicinity of the~~ near a pupil element (0) as ~~well~~ does ~~as~~ the value of l''_{Ω} ~~in the~~ at the point (0) in various cross-sections of the pupil element (0) ~~which~~ corresponding (cross-sections) to various normal cross-sections of

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the wave-surface element (0) [~~in~~ for all ~~locations~~ positions of the point (Ω) on the ray we still have $\mathcal{L}'_{\Omega}\big|_{\sigma_0=0} = 0$ ~~in the~~ at point (0)]. In the case of the anastigmatic wave-surface element (0), the wave-aberration surface point (0) ~~gradually~~ successively becomes: nonfocal umbilical -- umbilical -- nonfocal umbilical.

Intersection of the ~~conjunction~~ juncture of the normals to the wave surface with any focusing plane makes the point (Ω) an energy-dispersion spot. Each point (Ω) of the energy-dispersion spot can be ~~regarded~~ considered as ~~a~~ the center of the comparison sphere tangent to the wave surface at the point (0), the normal ~~of~~ from which contains this point and can be constructed for the point (Ω) ~~of~~ the wave surface aberration. Elements (0) of the wave-aberration surface corresponding to various points (Ω) of the dispersion spot in the given focusing spot, as the centers of the comparison spheres ~~which are~~ tangent (spheres) to the wave surface at ~~the~~ point (0), can be of five types: elliptical, hyperbolic, parabolic, umbilical, and nonfocal umbilical.

The properties were examined above ~~of~~ the isophasic line in the plane tangent to the wave surface at ~~the~~ point (0), from which the normal contains the ~~examined~~ studied point (Ω) of the dispersion spot. This normal coincides with the ray ~~going~~ arriving from ~~the~~ point (0) of the 'discharge pupil' system. The isophasic line ~~in the vicinity~~ near of the 'pupil' point (0) is ~~represented as~~ the projection from the point (Ω) of the isophasic line in the plane ~~which is~~ tangent to the wave surface at ~~the~~ point (0).

Start here

We can ~~arrange~~ agree to ~~call~~ name each point (0) of the 'discharge pupil' system ~~by~~ according to the type ~~to which~~ of the wave-aberration surface point (0) ~~belongs~~ (which is) constructed for the studied point (Ω) of the energy-dispersion spot belonging to the ray from the 'pupil' point (0). Thus for given positions of the luminous point and focusing planes, the 'discharge pupil' system points can be classified. They can be of five types: elliptical, hyperbolic, parabolic, umbilical, and nonfocal umbilical. Depending upon ~~the~~ the wave-surface structure and focusing planes, the 'pupils' can contain all ~~of~~ the enumerated types or some of them ~~may~~ can be absent.

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The ray from the umbilical 'pupil' point ~~occurs in~~ arrives at the focal nucleus. The ray from the parabolic 'pupil' point ~~in~~ arrives at the picture element of the focal lines. The ray from the elliptical and nonfocal umbilical 'pupil' points arrive at the outer diffusion element of the dispersion spot. The ray from the hyperbolic 'pupil' point ~~occurs in~~ arrives at the inner diffusion element of the dispersion spot.

To various normal cross-sections of the wave-surface element (O), there correspond cross-sections of the 'pupil' element (O) formed by these intersecting planes. We ~~will~~ shall call the cross-section of the 'pupil' element (O), corresponding to the main cross-sections of the wave-surface element (O), the main cross-section of ~~the~~ 'pupil' element (O).

The comparison sphere, constructed around a certain point (Ω) of the dispersion spot, as around a center, can appear tangent to the wave surface ~~in many places~~ at several points at the same time or ~~within the limits of~~ in a whole region ~~area~~ of its points. The normals to the wave surface of these points makes the 'pupil' points uniform or of various types. The light disturbances from these 'pupil' points arrive at ~~occur in~~ the point (Ω) in the same ~~a uniform~~ phase. At ~~In the~~ point (Ω), ~~there occurs the section of~~ the dispersion-spot elements of the same ~~a uniform~~ or different types. (A change of the comparison sphere, ~~which is~~ tangent at a certain point (O) of the wave surface, to one concentric with it, does not change the type to which the pupil point belongs. The comparison sphere, tangent at a certain point (O) of the wave surface, can appear concentric with the comparison sphere tangent at another point of the wave surface. The phases, with which the light disturbances arrive at ~~occur in~~ the point (Ω) from the corresponding pupil points, can appear ~~as various~~ different.

If the dispersion-spot point (Ω) does not belong to any normal to the ~~wave~~ surface, then the comparison sphere constructed around it ~~does~~ is not ~~appear~~ tangent to the wave surface at any point, and the wave-aberration surface constructed for it does not have any ~~"extreme" sections~~ extremal parts. The dispersion-spot element around such a point (Ω) is ~~diffusionary-diffractionary.~~ diffusive-diffractive.

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2. A Method of Experimentally Studying the Connection Between the of the Wave-Surface Structure and the Structure of the Energy-Dispersion Spots.

The proposed method (method of "eye" interferograms), which is easily accomplished on Twyman's[1] or Linnik's[2] interferometer, allows one to observe of the object under study in the discharge pupil plane, or in any other plane, the interferograms for various points (Ω) of the energy-dispersion spot, coincide with the center of the comparison sphere. Such an interferogram represents the above-examined family of isoberration (isophase) lines which describe the wave-aberration surface for the given point (Ω). the "eyes" of the interferograms. We shall call the elements correspond to the extremal parts of the wave-aberration surface for the point (Ω). The "eyes" specify the pupil elements from which the rays arrive to the point (Ω). The interference band near the pupil point (O), from which the ray comes to the point (Ω) coinciding (point) with the center of the comparison sphere, represents the projection from the point (Ω) of Dupin's indicatrix constructed for the wave-surface point (O). The "eyes" possess characteristic properties that depend upon the type to which the pupil point surrounded by them belongs. This permits one to experimentally classify the discharge-pupil point of the examined system for given positions of the emitter and focusing plane. One can The properties immediately observe of various types of pupil elements, and the nature of their formation, and their coordinates x, y determine. In particular, the region (and its area) one can observe which surrounds the pupil point (O) of a given type (from which the ray arrives at point (Ω)) and sends to the point (Ω) light disturbances with a difference phase exceeding beforehand amount (for example $\pi/2$). Simultaneously, one can the coordinates ξ, η of the point (Ω) experimentally obtain for which the interferogram and its "eyes" are observed. The type to which pupil point (O) sending a ray to the point (Ω) belongs determines the type to which

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the energy-dispersion spot element of the ~~in the vicinity of~~ near the point (Ω) belongs.

From ~~the~~ immediate observation ~~findings~~ of the interference pictures on the discharge pupil of the studied ~~examined~~ optical system, obtained (pictures) for various points (Ω) of the energy-dispersion spot, this spot one can ~~be~~ constructed; that is, ~~the~~ its focal nucleus, the picture of the focal lines and diffusion elements can be constructed and ~~an~~ evaluated ~~evaluation of~~ their brightness ~~made~~. At the same time, the geometric place of the pupil points one can ~~be~~ construct ~~structed~~ from which the rays arrive at ~~pass into~~ the points of the energy-dispersion ~~persion~~ spot of a given type. Immediately The role of various pupil segments can be evaluated in the formation of ~~forming~~ the image ~~description~~.

By a comparison of energy-dispersion spots, constructed with the aid of the interferometer, with those observed ~~the findings~~ in actually similar arrangements, one can relate the properties of various types of the energy-dispersion spot elements of ~~and~~ with the properties of the corresponding type of discharge pupil elements of optical systems, ~~were connected.~~

Thus, the proposed method of ~~the~~ interferogram "eyes" enables one to ~~ensures the possibility of an~~ immediate evaluation ~~evaluation of~~ the role of various ~~segments~~ parts of ~~the~~ a discharge pupil in the system in the formation of an image ~~forming the description of the~~ in a given element of its visual ~~pupil~~ field, and to describe ~~descriptive~~ the properties of the image.

The center of the comparison sphere, superimposed on ~~combined with~~ various points (Ω) of the energy-dispersion spot, in the case of Twyman's ~~Turyman's~~ interferometer is represented as the center of the spherical mirror ~~specific speculum~~ of the instrument. In the case of Linnik's interferometer it is represented by an opening which appears as the source of spherical diffraction waves. Joining the center of the comparison ~~compared~~ sphere with various points (Ω) of the energy-dispersion spot, one each time can ~~be~~ recorded ~~when~~ the coordinates ξ, η of the point (Ω) ~~are found~~ for which the interferogram is observed. On the other hand, one the coordinates of the pupil point can ~~be~~ registered ~~by the~~ by the interferogram ~~system~~, from which rays gg to point (Ω).

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In ~~Turyman's~~ Twyman's interferometer, instead of ~~joining~~ shifting the center of a ~~specific speculum~~ spherical mirror in a certain focusing plane, by maintaining its position fixed, the angle of inclination can ~~be~~ be changed between the wave-comparison plane and the waves arising from the ~~studied~~ under study object surface (surface of wave aberration). The coordinates ξ, η of the corresponding ~~to the~~ point (Ω) of the energy-dispersion spot, are easily obtained from the ~~values making up~~ components of this inclination angle. The obtained interferogram ~~also~~ appears as if the center of the ~~specific speculum would have been placed at~~ spherical mirror had been shifted to the point (Ω) with these coordinates ξ, η. Actually, from ~~the~~ a wave-aberration surface $l_{\Omega_1} = l_{\Omega_1}(x, y)$ for any point (Ω_1) of the dispersion spot, the ~~Decarte~~ Cartesian coordinates of which are ξ, η, one can ~~be converted~~ transform it to a wave-aberration surface $l_{\Omega_2} = l_{\Omega_2}(x, y)$ for any other of its points with coordinates ξ_2, η_2. To this corresponds ~~the~~ a shifting ~~joining~~ of the centers of the compared sphere in ~~an unchangeable~~ constant focusing plane, ~~in the dimensions~~ equal (shifting) to $\delta\xi = \xi_2 - \xi_1$, $\delta\eta = \eta_2 - \eta_1$. <p 311

If r is the distance from the discharge pupil of the system to the focusing plane and $\delta\xi, \delta\eta \ll r$, then the indicated transfer ~~occurs~~ is effected with the aid of the expression $l_{\Omega_2} = l_{\Omega_1} + Ax + By + C$ where A, B, E, are constants; : $A = \frac{\delta\xi}{r}$, $B = \frac{\delta\eta}{r}$ and C can be made equal to any constant ~~dimension~~ quantity. In other words, to the values of the wave aberration $l_{\Omega_1}(x, y)$, one adds algebraically the deviations ~~with their sign are added~~ from the x, y plane inclined ~~to the dimension~~ by an amount ~~which is~~ determined by the ~~values of the~~ coefficients A, B.

Thus, if, ~~in an unchanging~~ for a constant position ~~of~~ (Ω) of the center C of the ~~specific speculum~~ spherical mirror whose coordinates ~~are~~ ξ_1, η_1, the wave of comparison plane is turned relative to the waves ~~returning~~ arising from the studied object (or ~~vice versa~~ vice versa) by a certain angle u, then the obtained interferogram will be ~~such~~ the same as if the center of the ~~specific speculum~~ spherical mirror had been displaced from the point (Ω_1) with coordinates ξ_1, η_1 by the amount :

$$\left.\begin{aligned} \delta\xi &= Ar = u_x r \\ \delta\eta &= Br = u_y r \end{aligned}\right\}$$

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where u_x, u_y ~~make up~~ are the components of the angle of turn of and is ~~led~~ extended to the point (Ω_2) with the coordinates $\xi_2 = \xi_1 + u_x r$ and $\eta_2 = \eta_1 + u_y r$.

Interference bands (is a aberration lines) ~~in the vicinity of the~~ near 'pupil' points (O) from which the rays ~~come to the~~ arrive at a given point (Ω) of the dispersion spot, ~~combined with~~ superimposed (point) on the center of the comparison sphere, ~~have~~ possess a characteristic form ("eyes" of the interferogram), depending upon the type to which the 'pupil' point (O) belongs for the examined focusing plane and given position of the point emitter. Since the mentioned 'pupil' points (O) correspond to the experimental points (O) of the wave-aberration surface for the point (Ω), ~~then~~ the elements (O) of the interference picture ~~have~~ possess another characteristic property. They appear as "centers of disturbances" of the interference picture. This signifies that if the difference ~~is uninterruptedly changed of the~~ is continuously varied in optical paths between interference waves (for example, pressure of the finger on the interferometer) and ~~at the same time take~~ the interference picture is simultaneously observed, then it can be noticed that the bands of the picture are ~~combined~~ shifted, ~~drawn to~~ toward the indicated centers of disturbance or ~~scattering~~ away from them. The "centers of disturbance remain ~~immovable~~ immobile on the picture during this.

The following corresponds to an increase ~~of~~ in the difference of the optical paths between the interference waves. The bands diverge from the center of disturbance ~~in the~~ at point (O) of the picture, if the wave-aberration surface point (O) of is a maximum in the examined cross-section. The bands are drawn ~~to~~ toward the center of disturbance in the case of a minimum. If ~~the~~ point (O) ~~of~~ the wave-aberration surface is ~~the~~ a curvature point of in the examined cross-section, then the bands ~~from~~ on one side are drawn toward ~~to~~ the center of disturbance and ~~from~~ on the other side are drawn way from it.

Let rays pass through the point (Ω) coming (rays) from several 'pupil' points. Correspondingly there occur several centers of disturbance of the interferogram. ~~At an uninterrupted change of~~ During continuous variation in the inclination of the ~~comparison~~ plane (of comparison) wave ~~band~~ which determines the ~~location~~ position of the points (Ω) of the dispersion spot, the position of the points of its tangency

(In 1924, Perry made use of the phenomenon of "disturbance centers" in interferograms in order to measure the geometric aberration of objectives (3))

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to the wave surface arising from the studied object (wave-aberration surface) ~~is uninterruptedly changed~~ varies continuously. The wave comparison plane can be inclined so that the ~~adjacent~~ neighboring centers of disturbance of the interferogram are ~~displaced~~ shifted toward each other. ~~At this~~ The value of wave aberration between them ~~becomes~~ is made all the smaller and, at ~~a~~ for certain inclination of the wave comparison plane, it becomes equal to zero; both "disturbance zones" run together and ~~forming~~ form an extensions of each other. When "centers of disturbance" are drawn close to each other ~~and having~~ representing elliptical, hyperbolic, nonfocal umbilical 'pupil' points, then a parabolic 'pupil' point is formed in the corresponding cross-section. When "centers of disturbance" are brought together, representing parabolic 'pupil' points in their cross-sections ~~that are~~ orthogonal to the direction of approach, then an umbilical 'pupil' point is formed. If the "centers of disturbance" approach each other representing parabolic 'pupil' points in their cross-sections coinciding with the direction of approach, then a parabolic area of 'pupil' points is formed. In the formation of a parabolic 'pupil' point, the line joining the approaching "centers of disturbance" determines the main cross-section of the 'pupil' element which corresponds to the direction of the main cross-section of the wave ~~service~~ surface element.

~~Descriptions of~~ The described properties of elements ~~in~~ in a interferogram around 'pupil' points (O) from which rays go to the point (Ω), combined (point) with the center of the comparison sphere, permit ~~the~~ one easily to localiz~~ation of~~e these 'pupil' points (O) and to determin~~ation of~~e their type.

Thus with the aid of the interferometer, the energy-dispersion spot (its focal nuclei~~e~~, focal lines and diffusion elements) can be immediately constructed ~~on~~ at any focusing ~~point or~~ plane for any ~~location~~ position of the 'luminous point'. The geometric place of the 'pupil' points of a given type can be consturcted. In particular, the geometric place of the 'pupil' points can be constructed from which rays ~~come into~~ arrive at the focal elements of the dispersion spot. The caustic surface can be constructed for a given ~~location~~ position of the 'luminous point'.

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The above-indicated constructions are immediately obtained from observations of ~~findings on~~ the apparatus. The amount ~~size~~ of ~~the~~ turn of the wave of comparison plane relative to the wave surface arising from the studied objective gives the coordinates (ξ, η) of the dispersion-spot point (Ω). With the aid of an ocular micrometer provided with an additional lens, the coordinates of the 'pupil' points from which rays go to the point (Ω) are determined for ~~at~~ a given angle of turn of the wave of comparison plane. Using the above-described criteria, the type once determined to which these pupil points belong and, correspondingly, the type to which the dispersion-spot element around the point (Ω) belongs. The trace of ~~refers~~ the intersection of the caustic surface with the focusing plane for a given position of the 'luminous point' can also be constructed on the basis of ~~based on~~ the results of ~~the~~ work on a photograph of an ~~one~~ interferogram, as was done by Shyusaner [4]. To do ~~For~~ this it is necessary to use the very laborious half graphic, half calculation method. The above-described method particularly permits one to solve ~~a solution of~~ this problem from ~~the~~ immediate observations of ~~findings on~~ the interferometer noticeably faster and more conveniently. Actually the matter here leads to certain manipulations and readings ~~along the~~ scale. Moreover ~~However~~ the proposed method permits the immediate evaluation of the comparative brightness of the elements of the picture of the focal lines, the observation ~~finding~~ of the properties of the 'pupil' elements around the points of ~~the~~ various types and determination of their role in the formation of ~~the~~ detailed images ~~description~~.

Figure 1. Shows an interferogram photograph, obtained by the above-described method. Examples of discharge 'pupil' points of various types are included. The photographs were made with a ~~relate to~~ Tessar Zeiss ~~Tseyss's~~ photo-objective f = 300, 1:4.5 and were obtained in the light of a sodium lamp for ~~at~~ various angular distances to ~~of~~ the 'luminous point' from the optical axis of the objective and for various focusing planes. The white spot on the interferogram indicates ~~shows~~ the position ~~location~~ of the 'pupil' center (origin ~~beginning~~ of the coordinates). The dark points on the interferogram indicate ~~show~~ the position ~~location~~

(wavelength 589 millimicrons)

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of the ~~examined~~ (under examination) pupil points. The symbol d_s will designate the distances from the focusing plane, ~~having a~~ containing the focus of ~~"sagittal hypo"~~ the sagital cross-section of the pupil element around its center, to the ~~examined~~ (under study) focusing plane, read off along the main ray,

Fotograph 1. $\Phi = 20°$; $d_s = 0.0$; $\xi = -0.054$ mm; $\eta = 0$.

The pupil point is umbilical. The point (Ω) of the dispersion spot with the indicated coordinates, ~~to~~ which the ray comes from the examined pupil point, belongs to the focal nucleus.

Fotograph 2. $\Phi = 10°$; $d_s = -0.2$ mm; $\xi = -0.01$ mm; $\eta = -0.03$ mm

The pupil point is umbilical. The point (Ω) of the dispersion spot belongs to the focal nucleus. ~~Into~~ To this same point (Ω), a ray comes from the elliptical pupil point (below); ~~i.e.~~ that is the diffusion element of the dispersion spot is superimposed upon the focal nucleus.

Fotograph 3. $\Phi = 0°$; $d_s = -1.1$ mm; $\xi = 0$; $\eta = 0$.

Here there occurs ~~an area~~ a region of umbilical points ~~distructed~~ dispersed around the circle, from which rays pass to the point (Ω) of the dispersion spot with the indicated coordinates. The point (Ω) belongs to the focal nucleus. ~~In~~ To this point (Ω) ~~there~~ passes a ray from the pupil center, with which its nonfocal umbilical point coincides.

Fotograph 4. $\Phi = 0°$; $d_s = 0.0$; $\xi = 0$; $\eta = 0$.

In the pupil center and around it is ~~an area~~ a region of umbilical points. Rays from them pass to the point (Ω) which belongs to the focal nucleus. The point (Ω) coincides with the focus of the paraxial rays.

Fotograph 5. $\Phi = 15°$; $d_s = 0.0$; $\xi = 0.0$; $\eta = 0.0$

There occurs ~~an area~~ a region of parabolic pupil points and three of its elliptical points.

Fotograph 6. $\Phi = 23°$; $d_s = 0.0$; $\xi = -0.015$ mm; $\eta = 0$

There occurs ~~an area~~ a region of parabolic points and one elliptical.

Fotograph 7. $\Phi = 0°$; $d_s = -0.9$ mm; $\xi = 0$; $\eta = 0$.

Here there exist two ~~areas~~ regions of parabolic points, ~~distrubuted~~ dispersed in

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concentric circles from which rays pass ~~approximately into~~ close to one point (Ω). The point (Ω) belongs to an astigmatic focal nucleus. In the center ~~there~~ is ~~found~~ a non-focal umbilical 'pupil' point.

Foto graph 8. $\Phi = 12.5°$; $d_s = +0.9$ mm; $\xi = -0.015$ mm; $\eta = -0.036$ mm.

There occurs ~~an area~~ region of parabolic 'pupil' points from which rays ~~pass in~~ arrive at the point (Ω) with the indicated coordinates.

Foto graph 9. $\Phi = 25°$; $d_s = +2.1$ mm; $\xi = 0$; $\eta = -0.09$ mm.

The 'pupil' point is parabolic. The ray from it ~~passes~~ arrives at the focal element of the dispersion spot, ~~located~~ dispersed (element) around the point with the indicated coordinates. The direction of the main cross-section is shown by the dotted line.

Foto graph 10. $\Phi = 0°$; $d_s = -0.9$ mm; $\xi = -0.017$ mm; $\eta = 0$.

~~In~~ To the point (Ω) of the dispersion spot with these coordinates pass the rays from two parabolic 'pupil' points and one elliptical. ~~In~~ The the point (Ω) elements meet of two focal lines belonging to two bands of the caustic surface at.

Foto graph 11. $\Phi = 25°$; $d_s = +0.6$ mm; $\xi = +0.045$ mm; $\eta = +0.005$ mm.

~~In~~ To the point (Ω) with these coordinates, rays pass from two elliptical 'pupil' points, from two of its hyperbola points and from one parabolic.

Foto 12. $\Phi = 23°$; $d_s = +1.7$ mm; $\xi = +0.025$ mm; $\eta = 0$.

~~To~~ the point (Ω) with these points, rays pass from four 'pupil' points - three elliptical and one hyperbolic.

The dispersion spots, constructed with the aid of the interferometer, were compared with (those observed under) ~~findings in~~ actual conditions for the same lengths of light waves, ~~location~~ positions of the 'luminous point' and focusing plane. The purpose of the comparison was to study the properties of the dispersion-spot elements of various types in connection with the properties of 'pupil' elements from which rays pass ~~in~~ to these dispersion-spot elements. The ~~findings~~ observations and photography were ~~done~~ effect with ~~the~~ aid of an

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~~Instrument~~ apparatus with a nodal carriage placed before the collimator. In the focus of the collimator ~~circular~~ openings were placed of various diameter which were illuminated by a sodium lamp. The mechanisms of the ~~instrument~~ apparatus with the nodal ~~coverage~~ carriage ~~was~~ is the same as ~~Turyman's~~ Twyman's interferometer. In ~~the~~ place of the center of the ~~specific~~ spherical ~~speculum~~ mirror ~~was~~ is the objective point of the microscope. In place of the microscope's eyepiece ~~where again be~~ it is possible to place an ocular-micrometer or ~~speculum~~ mirror photo-apparatus with ~~a lockered~~ an unscrewed objective. In both instruments the ~~studied~~ under study object is so placed that its second modal point is ~~found~~ on the axis of its rotation. ~~There~~ is ensured the similarity of the focusing planes and the position of the luminous point on both instruments. Micro-objectives ~~apertures~~ were used with an aperture ~~which surpassed~~ exceeding the aperture of ~~the~~ a ~~studied~~ high-quality objective.

The schemes and photographs of Figure 2 illustrate the use of the above-described method of ~~working~~ operation with ~~Turyman's~~ Twyman's interferometer and compare the dispersion spot constructed with the aid of the interferometer with actual ~~findings~~ observations. The data, given ~~on~~ in Figure 2, relate to the Tessar Zeiss ~~Tessar~~ photo-objective f = 300, 1:4.5 ~~at~~ for an angular distance of the luminous point from the optical axis of $\Phi = 15^{\circ}$. The distance from the second nodal point of the objective to the focusing plane is 211.4 mm.

Interferograms describe the ~~location~~ position of the parabolic pupil points. Under each interferogram ~~where~~ are indicated, in microns, the coordinates ξ, η of the point (Ω) of the dispersion spot belonging to the focal line element, ~~at~~ to which the ray passes from the ~~examined~~ parabolic pupil point under discussion. In scheme 1 ~~there~~ are constructed the discharge pupils of the objective and on it the geometric ~~place~~ locus of the parabolic pupil points. Here the coordinates ξ, η are also indicated (expressed in microns) of the dispersion-spot points, ~~at~~ to which the rays pass from these pupil points. In scheme 2, the picture is shown of the dispersion-spot focal lines, which ~~were~~ (picture) is constructed with the aid of the interferometer according to ~~by~~ the above-described method. Around the points

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of this picture, the coordinates x, y are shown (expressed in millimetters) of the pupil points, from which rays pass ~~to~~ to these points. An enlargement is ~~not~~ shown here of the photograph of a dispersion spot obtained (photograph) by the apparatus with the nodal carriage under conditions ~~an arrangement~~, similar to those for which it was constructed by the interferometer. ~~The~~ arrangements, similar to those for Fig 2, were set up ~~constructed~~ for various angular distances of the luminous point from the objective axis and for various focusing planes.

Later it appeared possible, by way of certain readjustments of the interferometer, to observe ~~study~~ and to immediately photograph on the interferometer an enlarged energy-dispersion spot by the placing of dots ~~stains~~ ("probes") on it, making a dispersion-spot element to ~~in~~ which rays from the "eyes" of the interferogram pass. The latter are observed ~~found~~ and photographed simultaneously. Thus, the relation ~~connection~~ between the pupil elements and the energy-dispersion spot elements is graphically represented on photographs which can therefore be easily measured and analyzed ~~analised~~.

~~There occurs~~ a good correspondence exists between ~~of~~ the energy-dispersion spots, constructed with the aid of the interferometer, and actual observations.

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T. N. Fig 1 - Photographs

Fig 2 - Photographs and 2 complicated graphs.

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