Laser Measuring Apparatus Based on Using Bifocal Lenses

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ABSTRACT

In order to determine resolving power of electronic and optical devices and photo materials, first and foremost interference methods are considered to be used. For further development of the transmission of television systems with high-resolution there have been considered use of the following ranks of instruments: laser interference rezolvometer dissector, the laser polarization interferometer of longitudinal shear and acoustic and optical correlator. Authors mark the main advantages of LIR that works according to the scheme of polarization interferometer compared to LIR that works according the scheme based on the projective technique. Interference method gives much greater contrast. This proves that in the projection method with an increase in spatial frequency contrast of the test pattern falls and the results obtained by this method are be recalculated with taking into account dependence of ratio of transmission contrast focusing optics on the spatial frequency.

Introduction

Development of the transmitting television system with high resolving power (Toma, 2014; Karmakar & Mandal, 2015; Rosenfield, 2016) put before researchers' new challenges related to measurement of resolving power characteristics of such systems. Study of resolution/resolving power includes determination of maximum number of lines per unit length of 1 mm still visible separately, and the investigation of the dependence of modulation depth of the signal at the output of the system from the spatial frequency of the transmitted picture (Bretenaker, 2015).

Significant practical importance has the study of the interference-polarization field, which is created by two-component crystal optical lenses - bifocal lenses (BL), by the type BL-1 and BL-2, when they are placed in a coherent system with laser sources (Kim, 2014; Vedral, 2005; Meschede, 2004). Such lenses are useful in the development of coherent optical detection and ranging systems, communications and information processing, as well as in optic instrument engineering.

BL-2 of longitudinal shear, are highly sensitive to have a longitudinal shear and have opportunity to generate various types of interference raster (Akhmanov, 2004; Bykov, 2006; Bass & Decusatis, 2010). With a smooth movement of the convergent laser beam along the z-axis, they are used in optoelectronic devices, which significantly helps in the further processing of the information (image analyzers), the measurement of laser beam parameters (angular divergence, spatial coherence), and optical transfer functions of controlled objects (lenses).

Interventional two dimensional rasters that are obtained with use of BL-2 can realize a wide class of transfer functions (algorithms) for optical imaging, and can later be used to measure total optical transfer function (longitudinal and transverse) with a different type of micro, and photo- telephoto lenses in the coherent emission (Ersoy, 2006; Chang, 2005).

Interference rasters formed by crystal optical systems (such as double deflecting prism of critical angle of splitting and BL) can be used instead of the correlation supporting transmission-type indicators in acousto-optic devices of radio signals processing (Beuth, 2015; Vasavada, 2014).

Use of interference pattern at the input to code ultrasonic light modulators (USLM) to perform dynamic consistent filtration is a new and perspective field of research on the optimal engineering of in acousto-optic (AO) correlators operating in the whole range of short meter and decimeter waves (at the brought frequencies from 1 MHz to 1 GHz) (Devaux, Huignard & Ramaz, 2014).

Goal of the carried out research: For further development of the transmission of television systems with high-resolution there have been considered use of the following ranks of instruments: laser interference rezolvometer dissector, the laser polarization interferometer of longitudinal shear and acoustic and optical correlator.

Materials and Methods

Laser Interference Rezolvometer (LIR)

At the Figure 1 there is a double deflecting prism of critical angle of splitting. Special restructuring of raster frequency is not required, as the necessary set of spatial frequencies (0.5 + 200lin/mm) has been included in the aperiodic structure of the interference raster itself.

Two-crystal optical lens are bifocal lenses (BL) of type BL-1 and BL-2 (Figures 2a and 2b) have a noticeable effect slitting the beam (image). They are made of a uniaxial crystal, Iceland spar (CaCO3) in the form of a combination of two plano-convex and plano-concave lenses. The direction of the optical axis at the lens component has been shown in Figures 2. In contrast to the known systems (Fedorov, 1976) slitting angle (the angle between the o - ordinary and e extraordinary - rays) at the output of BL has a strong non-linear dependence from the angle of incidence. This property of the lenses of type BL-1 and BL-2 opens up a wide range of new opportunities for their application.
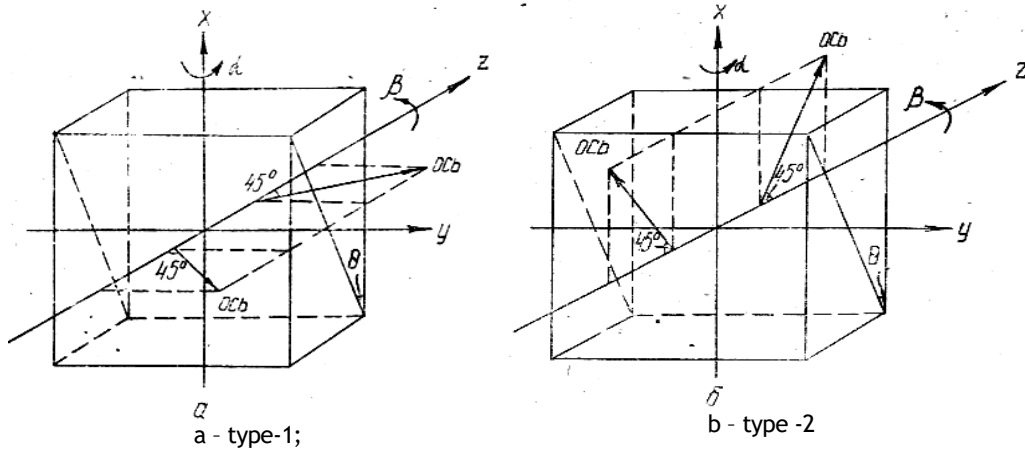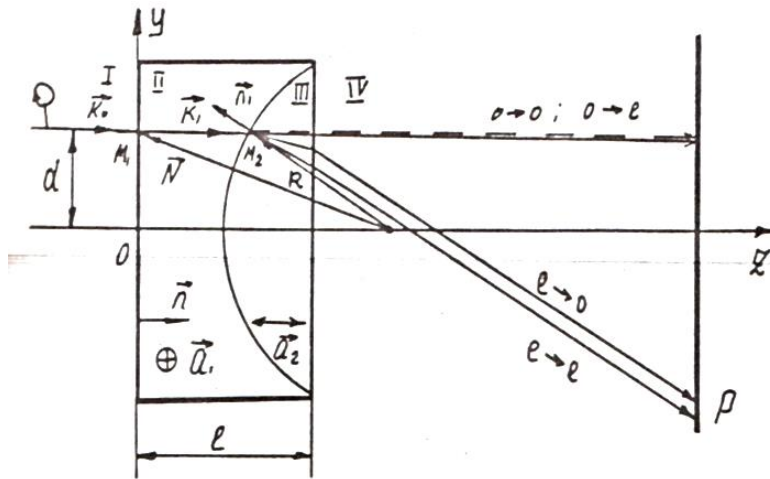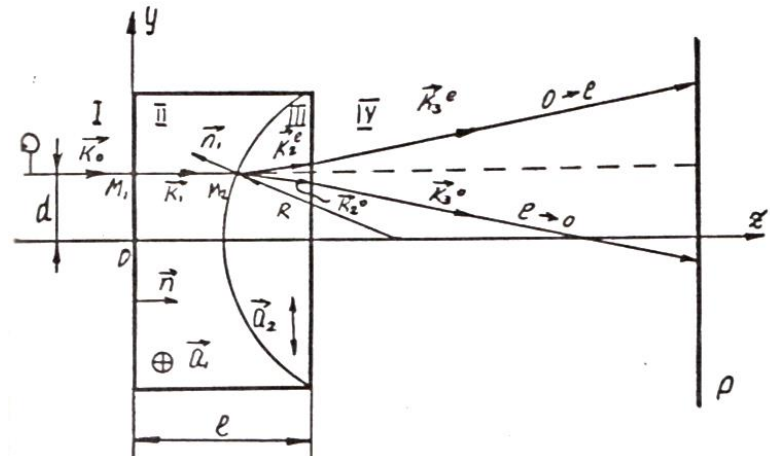
a – type-1;   b – type -2

Figure 1. Construction of double splitting prisms of the critical angle of splitting
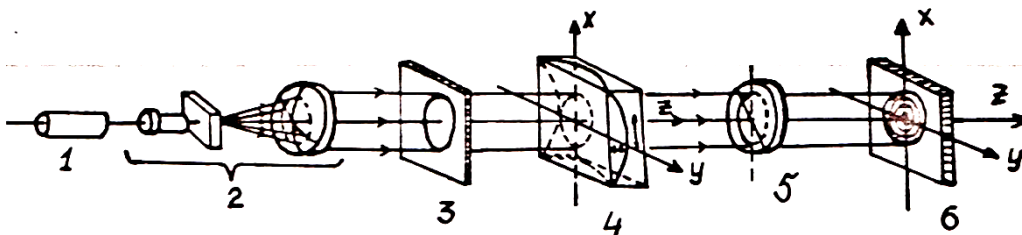

a – type BL-1;

b – type BL-2

Figure 2. Bifocal lenses

Optical Scheme and Characteristics of Resolvometer

LIR was assembled under the scheme of polarization interferometer shear of BL. The apparatus uses the mode of interference in the parallel light beam, wherein photo shift of orthogonally polarized beams at output of BL through the analyzer leads to formation of spatially non-localized interference pattern in the form of aperiodic rings.

Optical scheme of LIR has been represented at the Figure 3. Laser beam 1 is expanded and collimated passing through telescopic system 2 which consists of short-focused and long focused lenses, where at their co-focused position there is a diaphragm of micron dimensions has been put in order to highlight the central part of the beam. Thanks to this, an expanded laser beam evenly illuminates the outlet facet of 4 BL. A quarter wave plate 3 mounted in front of BL transforms the linear polarization of the laser radiation in the circular needed for equal intensities of the o- and e beams at output of in BL. Photo shift of orthogonal polarized beams takes place at the analyzer 5. Investigated system has been set up in the sphere of reconfiguration of interfering beams at the cross-section of which ring raster is formed in form of zoned picture of Frennel (Figure 3).

Spacious frequency of the ring raster enlarges from the center to the peripheral parts. Contrast can be adjusted from 0 to 1 by turning the analyzer around LIR axis. Contrast reaches 100% when setting of the polarization plane of the analyzer at an angle of 45 ° to the plane of polarization of the o- and e- beams when their intensities have been equalized.

1 – gas laser; 2 – telescopic system; 3 – quarter wave plate;
4 – bifocal lens of type BL-1; 5 –analyzer; 6 – image accepting system

Figure 3. Laser interference resolvometer at the bifocal lens

Both types of BL can be used in LIR. Bifocal lens of BL-1 type forms circular raster and coherent non-periodical lattice.

Bifocal lens of type BL-2 generates interference lattices of ring and hyperbolic types. The range of wavelengths, which can be operated by LIR has been defined by the zone of the transparency of the material that the BL has been made of. For Iceland spar - this entire visible and near infrared region of the spectrum ($\lambda = 0.3 + 2.3$mkm).

Rezolvometer with BL with a helium-neon laser ($\lambda = 0,6828$mkm) provides a spatial frequency up to 100 cycles per millimeter, which is sufficient to study the resolution of today's television systems

Results

Research of Resolving Power of Dissector with Use of Laser Interference Resolvometer

Among transmitting television tubes dissectors have the strongest resolving power capability/resolution capability. It is particularly important to have etalon pattern with big contrast of big spacious frequencies for their analysis. Interference method provides formation of such a pattern. Formation of such a pattern provides interference method. In contrast to the projection method with a rectangular illumination distribution of the test pattern of the world's interference method gives sinusoid illumination distribution all over the field that affects the form of the received contrast-frequency characteristics (CFC) of the tested photo target. Effect of illumination distribution of the test pattern on CFC dissectors can be estimated in the article A. Girard (1960) considering the perfect dissector as a device that registers the light flux incident on the photocathode section bounded by the cut of a hole which is run against of a raster with a corresponding change in transmittance. Maximum F max and Minimum F min of the light streams that fall to the sensitive area last for a second when Maximum and Minimum of illumination coincides with the middle part of the cut hole.
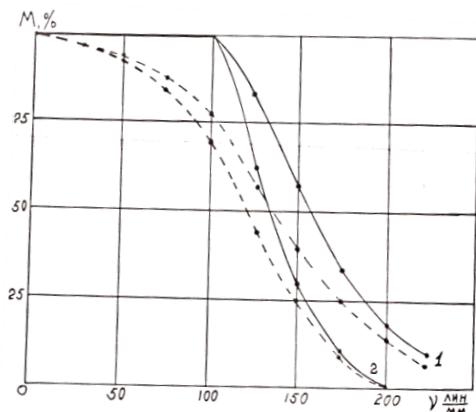
Calculated curves of the depth of the output signal modulation from the spatial frequency when there is a rectangular illumination distribution (solid line) and when a sinusoidal distribution of irradiance (dotted line) for a circular engravings opening diameter d = 10 microns (curves 1) and a width of 10 microns (curves 2) for rectangular engravings opening presents Figure 4. Dependence obtained shows that at high spatial frequencies (d close to T) CFC taken by various methods differ only slightly from each other, and at T = d drop to zero. In the low-spatial frequency CFC filmed in a rectangular illumination distribution is much higher than in the case of a sinusoidal distribution.

Contrast of rectangular distribution at 100% is transmitted up to T = 2d, and the contrast of sinusoidal distribution decreases starting with zero spatial frequency. Effect of the engravings of the hole affects the large spatial frequencies, where the circular hole provides a substantially higher transfer of contrast

Illuminance distribution of the test pattern on CFC and the impact on the shapes of dissectors must also be taken into account when comparing the characteristics obtained by the interference and the projection method.

Experimental research of dissector by means of interference rezolvometer was conducted on a round dissector engravings hole d = 10 microns. a circular raster in form of zone pattern of Fresnel was used for the measurement of CFC dissector. The results of the measurements of CFC dissector has been shown in Figure 5. Characteristics of filmed by the projection method of CFC of the same dissector (dotted line) coincide only in the low spatial frequencies, which does not affect the effect of focusing optics.

Given above LIR enables to measure CFC at different contrasts of interference raster that is achieved by the turn of analyzer 5 to the required (Figure 5, curves 3, 2).

Figure 4. Calculated curves of dependence of the depth of modulation of the output signal from the spatial frequency
Curves 1 – sinusoidal luminance distribution (dotted line) for a circular engravings bore diameter d = 10 microns; Curves 2 – engravings for the rectangular holes 10 mm wide

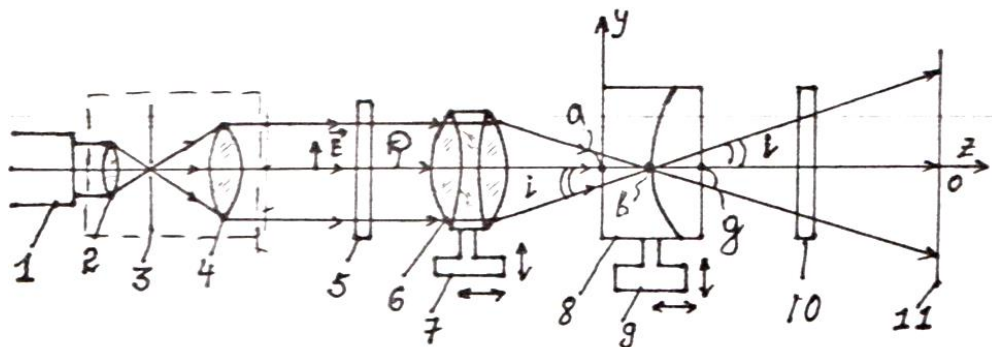## Laser polarization interferometer of longitudinal shear

Known devices (Batyrakov, 1981) operating on the principle of their actions are shear interferometers ie they allow to measure the path difference in the direction perpendicular to the axis of the instrument and can give information transmitted optical function of the controlled object only in the transverse direction (x, y).

The proposed device makes it possible to measure not only laterally, but in the longitudinal (along the z axis) direction and thus decides the important task of usage of the third dimension (longitudinal position) to increase the information capacity of optical systems.
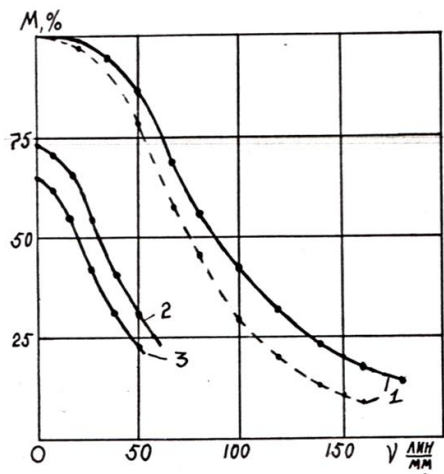
Figure 5. Changes of CFC of dissector
curve 1 engravings bore diameter of 10 microns captured by the interference method (solid line) ; curve 2 - projection method with recalculation to sinusoydal distribution (dotted line); Curves 2 3 - with different contrasts interference pattern: 1 at φ = 450 φ = 550 2When 3If φ = 580 where φ -angle between the analyzer direction and one of the vectors E_e and E_o

Functional diagram of the longitudinal polarization shearing interferometer is shown in Figure 6. The device operates as follows. The laser beam from the source 1, after the expansion of its collimator includes a microlens 2 the diaphragm 3 and the collimating lens 4. With the quarter-wave plate 5 is converted from linearly polarized circularly polarized and coherently illuminates a controlled object (eg. a lens) which is moving with the help of table 7 focuses the laser beam to a point with coordinates x y, z, inside or outside of BL -2. The laser beam with an angle of convergence, and, passing through the BL-2 splits into two beams: ordinary (o) and extraordinary (e), and the difference of path between the o- and e- beams depends on the focus position. Next o- and e beams with orthogonal polarization get into analyzer where they photo shift, and there is space non-localized interference in the form of alternating light and dark stripes of the defined contour. For a little contrast of fringes analyzer oriented at angle of 45 to the optical axes of BL-2. Interference raster visualizes on the screen II that is placed on a remote order of 20 cm or more from BL-2.

Figure 6. Laser polarization interferometer of longitudinal shear
1 - a gas laser; 2 - microscope objective; 3 - the diaphragm; 4 - collimated lens; 5 - quarter-wave plate; 6 - controlled lens, 7.9-tables; 8 - bifocal type BL-2; 10 - analyzer; 11 - screen or photodetector system

For small angular or linear displacement of the controlled object 6, as well as upon changes of the convergence angle the shape of interference raster changes. Restoration of the original form of the raster has been achieved through 3D (3-dimentional) control of smooth movement of the BC-2 with help of a precision table 9. For hyperbolic interference raster which is formed at the central (axis symmetrical) displacement of a focused laser beam inside the BC-2 (point "B" in Figure 7) hyperboles will be equilateral toward AB and CD (Figure 7), and when the focus shifts at the point "a" and "d" in Figure 6, hyperboles gradually become non-equilateral. For a fixed point in the BC-2 with change in angle i the number of hyperboles will change too. For a given angle i of the laser beam convergence difference of path of interfering beams in BC-2 is conveniently measured by the number of stripes observed in the screen II in the direction "y" axis, i.e. at an angle of 45° and symptoms-free AB and CD (Figure 7).

Comparing to the famous interferometers the suggested device enables to research light beams with the big angle of convergence (of around 40°), and when using the regime of Longitudinal shear (along Z axis) to increase the aperture of the investigated light beam.

The range of measured displacements of the focused laser beam along the z axis in the intended interferometer is about 40 mm, and there are 15 cm on the

displacement (shift) on the left and right of BL-2 faces. Given range of shift corresponds to a cycle of reproduction of specific type of interference pattern that have its mathematical description.
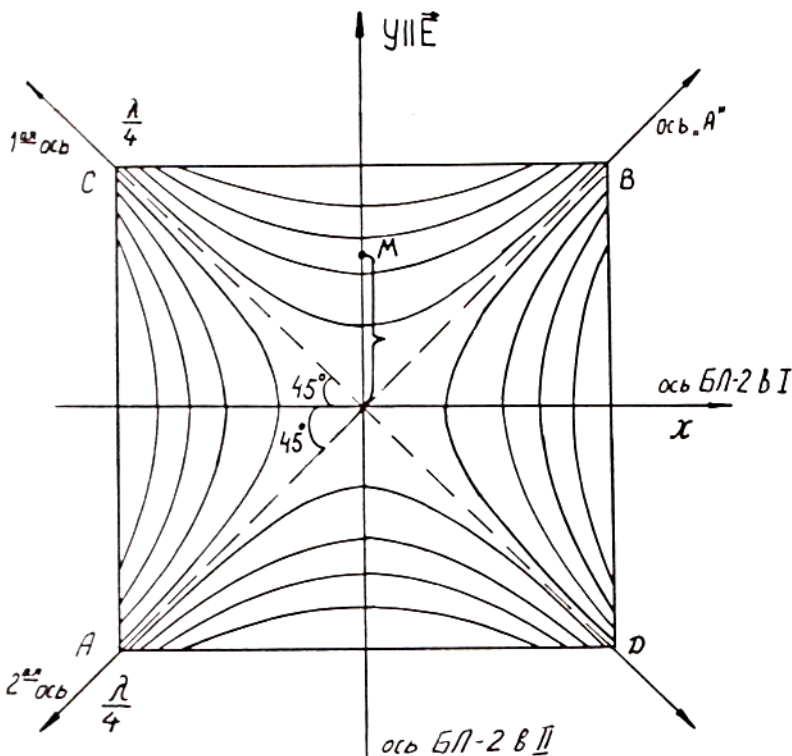
Figure 7. Hyperbolic raster generated by BL-2 in the convergent laser beam

Acoustic and optic correlator

Hereunder we offer possible technical solutions to create acoustic and optic correlator with use of crystal optic systems. Known devices (Makushev, 2000) differ from each other by the way of registration of correlation signal: either in direct Fourier transform plane (frequency plane) or in the inverse Fourier transform plane (image plane). The main disadvantage of most known acousto-optic correlator is the presence of transmission-type indicators (Koliteevskyy, 2006), the technology of manufacture of which is relatively difficult and their usage reduces performance characteristics and reliability of real devices and also the drawback of the known acoustic and optic correlator is the small range of measurement of correlated radio signals.

Suggested Acoustic and optic correlator widens measurement range of correlated radio signal on keeping its high precision of detection of radio signal. The Goal is achieved by realization of two options.

First variant. In order to achieve the assigned goal in Acoustic and Optical correlator between the source of collimated circularly polarized, homogeneous, optical radiation and ultrasonic light modulator double reflecting prism of critical angle of splitting (doubling) and polarizer have been set up on one axis by Acoustic and Optical correlator, so that double reflecting prism of critical angle has been fixed to the rotary limb, axis of rotation of which is perpendicular to the axis of AO

correlator and the polarizer is oriented perpendicular to the axis of AO correlator and at an angle of 45 ° to the plane containing the optical axis of double reflecting prism of critical angle of splitting (doubling), the optical axis in both wedges mutually perpendicular and are arranged in a plane perpendicular to the front faces and the edge of the prism.

Second variant. In the contrast to the first variant in order to achieve the goal in the Acoustic and Optical correlation instead of double reflecting prism of critical angle of splitting (doubling) lens and bifocal lens have been set up when the sens has been fixed at the table, the direction of movement of which coincides with the axis of acoustic and optical correlator and a the polarizer is oriented at 45 ° to the optical axis BL, the optical axes of a plano-convex and plano-concave lenses BL mutually - perpendicular and are arranged in a plane parallel to the input and output faces of the BC and perpendicular to the axis of the given acoustic and optical correlator.

In the suggested device an interference system has been set up instead of reference transmission type indicator, system that forms the light field in form of interference raster, spatial (carried) frequency and lines profile of which can change smoothly in the wide range. Interference raster resets by turning of dial (limb – first variant) or by moving of the table (second variant) at which interference system is fixed.

The device is explained by the drawings at the Figures 8-10. Acoustic and Optical correlator (Figure 8a.) contains sequentially located on the same axis collimated source 1 circularly polarized, homogeneous, optical radiation, an interference system 2) Ultrasonic light modulator 3 to the piezoelectric converter 4) to which correlated radio signal $S_C(t)$ has been put, lens 5 (of the direct transformation by Fourier), a photodetector 6, located at the focal distance f for registration of the signal $S_{B_x}(t)$, in diffraction maximum of the first order, a diaphragm 7 to highlight the diffraction of the first order.
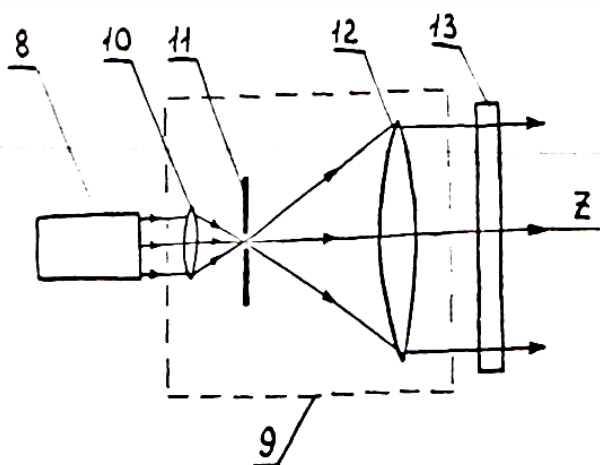
Source 1 collimated circularly polarized, homogeneous, optical radiation (Figure 8b) comprises a laser 8, the collimator 9, which serves to expand the laser beam and consists of the microlens 10, the lens 12 and the aperture 11 micron-sized, installed in a confocal position, quarter-wave plate 13 for transforming linearly polarized beam into a circularly polarized beam.

The interference system 2 depending on the type of correlated radio signal has been represented in two variants (Figures 9 and 10).

Interference system of the first option of acoustic and optical correlator that is shown at the fig. 9a, contains fixed at the axis of acoustic and optical correlator double deflecting prism of varied angle of doubling (splitting) 14, mounted on the limb 15 and a polarizer 16, when the axis of rotation of limb 15 is perpendicular to the axis of rotation of acoustic and optical correlator 14 of double deflecting prism of varied angle of doubling with an angle α=45°, which consist of two glued together wedges 17 and 18 of uniaxial Iceland spar crystal cut at an angle to the optical axis at 45°. Moreover, the optical axes of both wedges are mutually perpendicular and are arranged in a plane perpendicular to the output faces and edges of the prism.
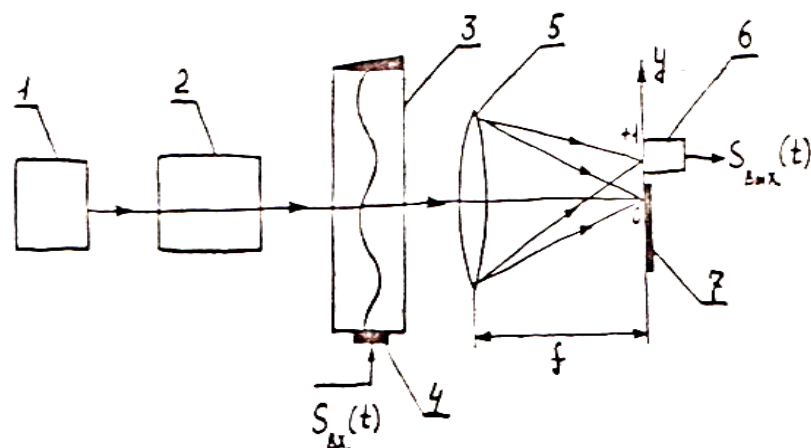
Figure 8 a. Acoustic correlator –Acoustic and Optical correlator (AO) and (b) Source of collimated circular polarized light

1 – source of polarized light; 2 – interference system; 3 – Ultrasonic light modulator - USLM; 4 – piezoelectric converter, 5 –lens, 6 – photodetector 7 - Aperture, 8 – gas laser; 9 –collimator; 10 - microlens; 11 - a diaphragm; 12 - lens; 13 - quarter-wave plate

Due to the specified orientation of the optical axes and the angle θ=45° is obtained greatest slope of doubling o- and e-rays and achieved a maximum range of tunable frequency interference raster (from 1 to 200 mm lines). Interference system of the first option of acoustic and optical correlator forms the spatial analog of sinusoidal signals and is used for their correlation analysis (Figures 9b and 9c)

Interference system for the first option of acoustic and optical correlator forms spatial analog of sinusoidal signals and has been used for correlation analysis (Figures 9b and 9c).
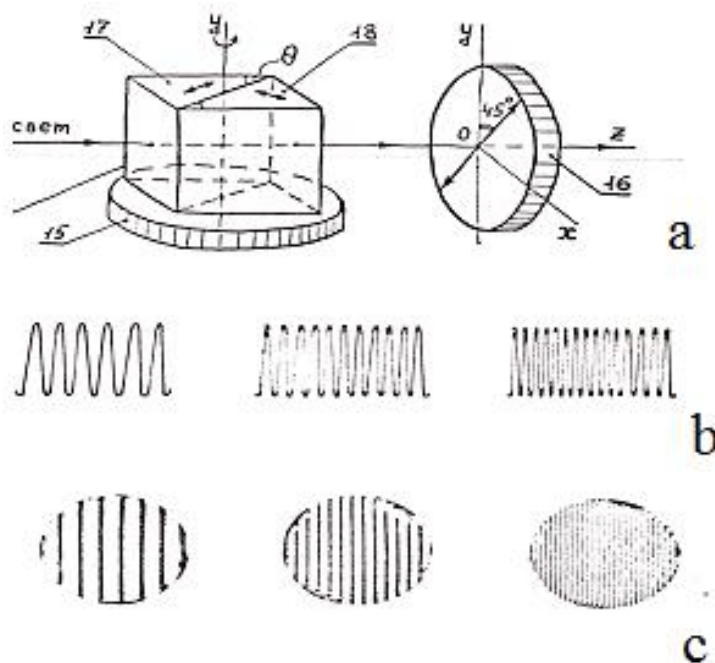
Figure 9. Interference system: **(a)** – 14-double deflecting prism of varied angle of doubling (splitting); 15-limb, 16-polarizer, 17-18 wedges of double deflecting prism of varied angle of doubling (splitting); **(b)** – interference rasters, which are formed by double deflecting prism of varied angle of doubling (splitting); **(c)** – sinusoidal signals from interference rasters formed by double deflecting prism of varied angle of doubling (splitting)

Interference system for the second option of Acoustic and optical correlator contains fixed at the axis of AO correlator lens 19, bifocal lens (BL) 20 and polarizer 21, when lens is mounted at the table, the direction of movement of which coincides with the axis of correlator (axis Z). In the second variant interference system forms spatial analog of linear frequencies modulated (LFM) signals and has been used for correlation analysis (Figures 10b and 10c).

Due to this orientation of the optical axes and the angle of $\theta=45°$ it is obtained the greatest slope of doubling of o- and e-rays and is being achieved a maximum range of tunable frequency interference raster (from 1 to 200 mm lines).

The interference system for the first option of acoustic and optical correlator forms a three-dimensional analogue of sinusoidal signals, and is used for their correlation analysis (Figures 9b and 9c). Interference system for the second variant of acoustic and optical correlator (Figure 10) contains set on the axis acoustic and optical correlator lens 19, a bifocal lens (BL) 20 and the polarizer 21, the lens 19 is fixed at the table 22, the direction of movement coincides with the axis AB correlator (axis Z.) in the second option, an interference system generates three-dimensional analogue of linear frequency modulated (LFM) signal, and is used for their correlation analysis (Figures 10b and 10c).
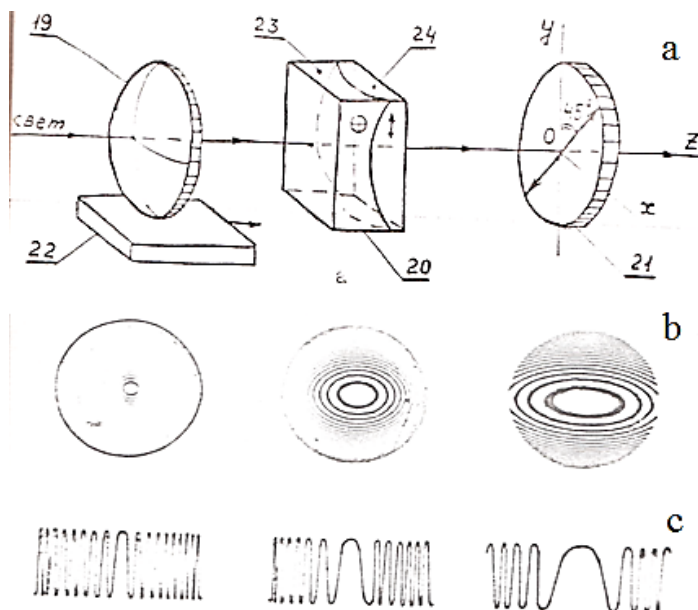
Figure 10. Interference system II: **a** – 19-lens, 20 –bifocal lens (BL-2), 21 –polarizer, 22 – table, 23, 24 – components of BL-2; **b** – interference rasters, that are formed by BL-2; **c** – linear frequency modulated (LFM) signals of interference rasters, that are formed by BL-2

The apparatus operates as follows:

Collimated circularly polarized, homogeneous, optical radiation from the source 1 goes through the interference system 2 and is converted into two orthogonally polarized beams: ordinary (o) and extraordinary (e) having an optical difference of path depending on the orientation of the interference system related to the coordinate axis x, y and z in the first option, this is achieved by turning the limbs 15 around the axis y, and the second option - by moving the table 22 along the z axis. After passing the o and e beams through a polarizer (16 - in the first option, 21 – in the second variant) oriented at an angle of 45° with respect to changes in the electric vector of the o- and e- beams there has been formed an interference raster with a structure correlated with a radio signal that have 100 % modulation depth and illuminates ultrasonic light modulator 3.

Correlated radio signal S(t) has been transmitted to the piezoelectric converter 4 and ultrasonic light modulator (USLM) which converts the radio signal into acoustic waves spread in the acoustic line of USLM. Structured light field in the form of interference raster illuminates USLM 3, passes through the acoustic waves by diffracting them. When the period of interference raster coincides with the length of the acoustic wave, which is analog of the radio signal photodetector 6 placed at the focus of lens 5 that operates direct transformation by Fourier registers correlation signal in the first-order diffraction maximum.

Thus, the diaphragm 7 serves to eliminate all diffraction orders, except the first. On smoothly changing spatial (carrier) frequency of interference raster through changing of the orientation of the interference system, it is possible to change measured range of correlated radio signals. At the same time, a complete harmonization with the acoustic wave (matched filtering), which provides highly

accurate detection of the radio signal is being achieved by the smooth adjustment of the carrier frequency of the interference of the raster.

Discussions

The devices shall meet the following requirements for better exploitation: simplicity of the construction and reliability in exploitation (vibration resistance); formation of interference picture with 100% depth of modulation at the whole surface of photosensitive cathode (of about 20мм²); high intensity of the interfering beams for the dissectors, high-resolution, small graved holes (of 3 + 10 microns); smooth adjustment of contrast of the interference pattern to study the transmission of television tubes at low contrast of sinusoidal lattices.

In comparison to the known laser inference resolvometers which are assembled under the scheme of the polarization interferometer shift to a bifocal lens the described device has several advantages: simplicity of design, configuration, and operation; it does not require the spatial frequency tuning; has a two-dimensional character of the ring lattice that allows it to apply for the analysis of the quality of two-dimensional transmission signals at various points of photo targets through anamorfism of image on the internals; It does not require a projection lens, and therefore do not need to make any amendment to its own contrast frequency characteristics (CFC) of lenses; measurement can be carried out over a wide spectral range from Ultraviolet (= 0,3mkm) to Infra-red (= 2.3mkm); range of spatial frequency that is overlapped by LIR (from zero to 100 mm line pairs) sufficient for metrological studies of transmitting television tubes and other optical-electronic devices; increased vibration resistance caused by the fact that the interfering beams are formed by a single element; continuous tuning contrast test pattern

Thus the laser polarization interferometer longitudinal shear compared to the known devices has the following advantages: 1. expands the functional opportunities of the polarization shearing interferometer; It has the ability of high-precision measurement of longitudinal shear, while maintaining a high sensitivity to the transverse shear; It can also reach a large range of measured longitudinal movements (about 40 mm); expanding the range of measurement of laser beam convergence angles up to 40° occurs; 2. simplifies the design of the interferometer, the interfering beams that are formed by one optical element; 3. The setting is simple, reliable and vibration resistance.

Acoustic and optical correlator has the following advantages: expands the measurement range of correlated radio signals, i.e. provides rearrangement Acoustic and optical correlator in accordance with the change in correlated radio parameters such as within one or two types of radio signals (for example, sinusoidal Linear Frequency based Modulated signals) through smooth restructuring as a carried frequency, so and an interference profile lines of a raster; improves the accuracy of detection of radio signal as the main restructuring of the carried frequency of the interference of the raster allows to make almost perfect setting of Acoustic and Optical correlator as a matching filter.

Conclusion

With an increase in spatial frequency difference between the curves obtained by different methods are becoming more distinguished Interference method gives much greater contrast. This proves that in the projection method with an increase in spatial frequency contrast of the test pattern falls and the results obtained by this method are be recalculated with taking into account dependence of ratio of transmission contrast focusing optics on the spatial frequency

Measurements made with use of LIR on BL-2 differs by one that the analysis of CFC by spatial parallel channels in the plane of the tested photo target.

Represented carried out comparisons have shown the advantages of interference method to form tested picture.

Disclosure statement

No potential conflict of interest was reported by the authors.

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