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Advancements in the Interferometric Measurements of Real Time Finishing Birefringent Filter's Crystal Plates

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Abstract. The finishing of birefringent plates consists of two processes: polishing and evaluation of a surface, which have been performed separately till now. The purpose of this work is achieving of high accuracy of the evaluation and machining of the plane-parallel plates from birefringent crystals, in particular of crystal plates of birefringent filters during their finishing.The developed process combines evaluation and polishing in an interactive way. We have found modes of treatment, shape of polisher, have designed interferometer, with a mirror arranged in polisher. Visual checking of optical thickness comparatively with reference plate was carried out using the interference fringes of equal birefringence, and checking of an optical wedge - by interference rings of an equal inclination. The automated processing of TV camera interference fringes was impossible, because of gaps of interference fringes on polishing cells above the mirror. Therefore a special software was developed for processing of a complex fringe pattern interferogram. Software FastInterf uses furrier analysis technique which allows to process an interferogram with multiply gaps. Interferograms are registered by a high resolution TV camera (1280 x1024). Automatic processing of a fringe interferogram using FastInterf software takes less then one second. The influence of gaps is excluded, and the flat field is taken into account. Software provides full 3D surface and wavefront maps. Aberration analysis of a wavefront gives information on thickness of a plate comparatively with a reference one, optical wedge of plate and azimuth of an inclination of wave front. Moreover, software provides a control of surface quality. The measuring device, features of the software are described and process of interferometric evaluation during polishing is illustrated.

1. Introduction

Classical birefringent filters (BF) did not exhaust their potentialities [1-9]. Researchers of the Sun are very interested in high contrast and transparency wide field BF with passband less than 0.1Å. BF should be tune on different solar spectra lines. Theoretically such filters might be designed with use large quantity of polarization stages. In practice its manufacture involves difficulties of optical processing and test about one hundred crystal plates with severe technological tolerances. For calcite plates the total tolerance for thickness plane parallelism and flatness is about 0.05μm for blue spectral range.

2. Finishing of BF crystal plates

Finishing of crystal plates consists of two iterative processes: polishing and optical test. During polish of crystal plates a geometrical (optical) thickness is changing therewith a flatness and plane parallelism are sustained the same. Sometimes a polish becomes difficult because of a surface astigmatism of anisotropic crystal plates. The process of polish is usually stopped for testing of thickness. Crystal plates are removed from zone of processing. Measurements of optical thickness are carried out either on spectrograph at BF working temperature by following a position of maximum spectral transmittance of polarization stage or polarization interferometer comparing interference fringes of processed and reference plates [10].The test needs much time because temperature of the plates should be equalized. Result of test can display the necessity a very small additional polish to get required thickness. On the other hand an allowance may be not enough to smooth surface which can be spoiled at the very beginning of iterative polish. The reasons of spoiling are temperature gradients in plates and difference between temperature of the polisher and plates which removed from polisher for test.

Hence, the finishing of BF plates consisted of two separated processes brings on spoilage very often We combined the polish and testing, found regime of precise treatment and designed polarization interferometer to test thickness of processed plates relative to reference one just directly on machine during polish.

3. Combining the processes of treatment and checking

We determined crystal working conditions on a machine where no astigmatic surface bending arises and a high surface quality is ensured. A device was also developed for checking the thickness and plane-parallelism directly during the polishing. Polishing and checking of crystal plates are integrated into a single technological process.

The main factor that leads to an astigmatic treatment of plates is the anisotropy of the coefficient of thermal expansion. Only the elimination, within the required limits, of the temperature gradient between the upper, dry and lower (i.e. that being polishing) wet surfaces can do away with the astigmatic bending of the component when treated in separator. Using thermistors placed in the surfaces, we examined the appearance and influence of temperature gradients upon the polishing process. When treating the plane-parallel plate of optical calcite of 10 mm thickness and 43 mm in diameter, astigmatic distortions of the surface were found to be about 0.1λ, with the temperature difference of the lower and upper surfaces less than 0.1°C.

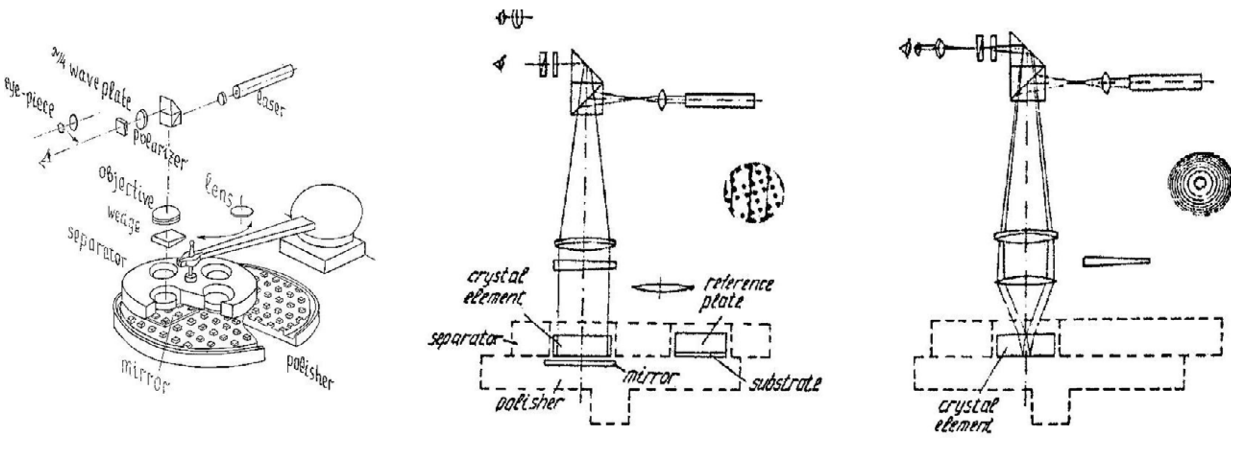

Figure 1. Device for polishing and simultaneous checking of crystal plates.

The Figure 1 (left) presents a schematic view of the device for the finishing of plates of birefringent filters. The device includes a polisher with teeth on which abrasive grains within a thin layer of the polishing pitch are secured. The adjusted crystal plates and reference birefringent plate are placed in the holes of the separator. The reference plate is installed on a thin transparent non crystal substrate, which protects it against polishing. The substrate allows the reference plate to take the same temperature as do the adjusted plates. It does not interfere with birefringence measurements. Above the polisher is an optical monitoring device. The device includes a point source of polarized monochromatic light, namely a laser with a microobjective lens, a beam splitter, an auto-collimation objective lens, mirror in polisher and a Senarmon compensator (a quarter-wave plate with a polarizer). The system can further incorporate an eye-piece, a crystal wedge, and a lens. The device is designed for measuring the optical thickness of crystal plates in birefringence as well as measuring plane-parallelism in n_o and n_e–beams. Plates are checked during a short -duration stop of the polishing process.

Figure 1 (middle) shows the scheme for checking the optical thickness. The light from objective lens of collimator passes through the crystal plate being monitored, is reflected by the mirror, passes again through the plate and from the beam splitter enters the Senarmon compensator. Based on the difference in the angles of the orientation of the analyzer to "darkness" for the reference and adjusted plates that are exposed to the same temperature, one decides if subsequent polishing is required. If the plates include the local optical inhomogeneity, then position of "darkness" is determined with low confidence. In this case checking should be carried out with a crystal wedge, which is introduced ahead of objective lens. The wedge, at a combined action with the plate, produces two or three interference fringes of equal thickness whose position depends on the thickness of the plate being processed. Dark circles on interference wedge pattern (Figure 1) are holes in mirror of polisher.

Plane parallelism of the components in n_e and n_o-beams is monitored with this same autocollimation device from interference fringes of equal inclination (Figure 1, right). The eye-piece and the additional lens are introduced into the system, and the wedge is withdrawn. The plate is put under into device with any position of the polisher, and no mirror is required for monitoring. Light beams that are reflected from the lower and upper surfaces interfere and produce, in effective focal plane of the device, interference fringes which are observed through the eye-piece. The wedge of the plate is measured in the direction of largest expansion of the fringes when the plate is displaced and it adjusted in the course of polishing. The pattern of equal inclination is also shown here.

4. Further development of the finishing

In the act of being treatment and tested human activity is steel important. Visual measurements of fringe or ring positions are difficult and subjective to make a right decision of machining conditions. Processing speed with good results or otherwise a quantity of spoiled expensive crystals depends on professional skill and experience of optician. Using of photoelectric control with double beam polarization interferometer and software [11] had made substantial contribution to development of the finishing.

5. FastInterf software adaptation for interferogram processing

FastInterf software destined to restoration of wave front phase using fringe interferograms, permits accomplish interferometric test of optical surfaces. Fast Fourier Transform of CCD-registered interferogram is used for phase restoration.

The wave front deflection from reference surface can be represented as a sum of smooth regular and irregular components. The last one describes local errors. The smooth regular component is represented by Zernike polynomials. These polynomials are easy correlated with classic aberrations. The separate types of aberrations represented by such expansion effect on image quality independently.

The smooth regular component contains standard errors such as constant, tilt, defocus, astigmatism, coma etc. (Figure 2). The values of these errors give information about tilt and azimuth of wave front under consideration relative to reference front.

Name	Value	Angle,°	Reliability	RMS(...	Comment
☑ C	0.76		1.11e-016	1.9	constant
☑ T	3.94	-41.3	0.987	0.025	tilt
☑ A2	0.0596	64.8	0.000636	1.9	astigmatizm 2
☑ D	0.00528		-0.000161	1.9	defocus
☑ Tr3	0.0243	70.3	-0.000154	1.9	trefoil 3
☑ C3	0.0223	143	0.000601	1.9	coma 3
☑ Q4	0.021	21.2	0.000196	1.9	quadrafoil 4
☑ A4	0.00901	4.69	-0.000158	1.9	astigmatizm 4
☑ S4	-0.00902		0.000233	1.9	spherical 4
☑ Pn5	0.0251	-8.51	-0.000189	1.9	pentafoil 5
☑ Tr5	0.0122	67.4	-8.78e-...	1.9	trefoil 5
☑ C5	0.00627	-129	-2.38e-...	1.9	coma 5
☐ local				1.9	local errors

Figure 2. Table of main aberrations.

The interference pattern observed during crystal plates finishing contains fringes as well as picture (image) of teeth of polisher. The additional peaks on the Fourier spectrum of such interferogram distort restored wave front. To prevent such distortions it is necessary to exclude from processing the areas of teeth image.

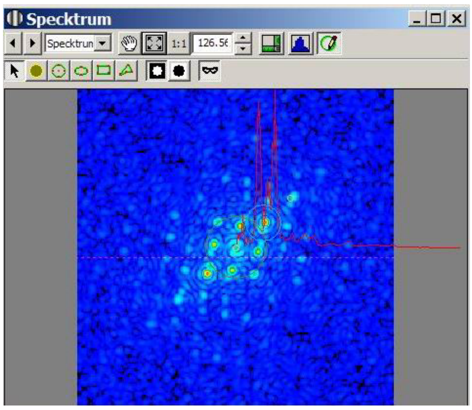

Figure 3. Fourier spectrum of interferogram with polisher teeth.

The aperture cutting out the pictures of teeth is superimposed on interferogram. Figure 4 is the example of such interferogram

In the first software variant the areas of teeth were excluded from calculations. But restored phase distribution had some distortions and 3D wave front pictures showed holes (Figure 5).

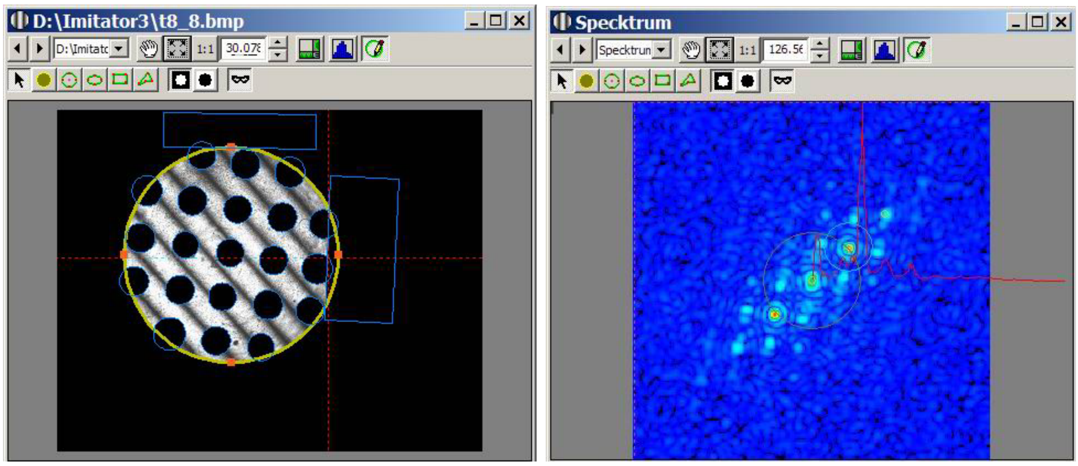

Figure 4. Interferogram with aperture mask and its Fourier spectrum.

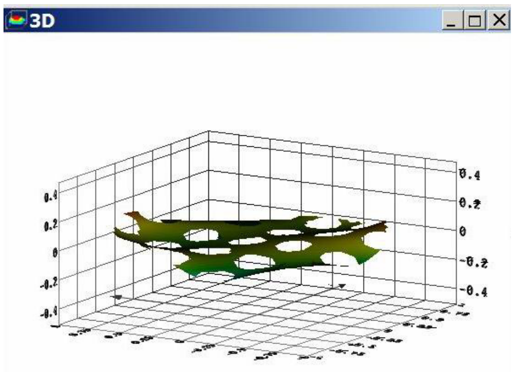

Figure 5. 3D picture of restored wavefront.

In adapted version of software the interpolation for excluded areas is performed at phase restoring. As a result the restored interference pattern has no distortions and 3D picture don't contain gaps. The adopted version saves imposed apertures in separate file. There is no necessity to create the aperture mask for each interferogram anew during processing of interferogram sequence.

Application of FastInterf for processing of polarization interferograms obtained with crystal wedge on polish machine will give quantity information of BF plate polishing in real time. Such calculated parameters as constant, tilt and azimuth (angle) of wave front tilt (Figure 5), which are not crucial parameters for analysis surface forms can be rightly applied for test thickness and wedge of crystal plates under treatment.

The finishing of crystal plates is realized relatively to reference plate. As a rule the allowance of thickness for polishing is no more than about one interference fringe. FastInter can calculate the difference of two wave fronts. If we take wave front of referent plate as the comparative then "constant" parameter will give optical thickness difference of the treatment and reference plates. The "point pressure" direction of polarization interferogram is direction of crystal wedge. The sign of wave front tilt is determined by known fact that treated plate is thicker than referent one.

The one fringe shifting in interferometer with crystal wedge means taking away the 1.8 μm allowance for optical calcite in double way pass for λ 6328 Å.

The tilt of wave front and its azimuth calculated according to measurements relative to reference plate wave front signify the amount of wedge to polish during finishing in the direction of calculated azimuth. Such parameter as wave front astigmatism might be useful to choice conditions of surface treatment .

Only interferogram with crystal wedge is sufficient for FastInterf to determine the sign of wedge. Number of fringes in our experiment is augmented till eight to increase the measurement accuracy and to take into account the local errors. In future it is intended to manufacture quartz wedge forming 12-15 fringes on treated plate which is 45mm in diameter.

6. Finishing of plates with FastInterf

The device for finishing of crystal plates showed on Figure 6 includes optical machine, birefringence interferometer with mirror built in polisher, CCD camera (1280x1024 pixels) for photoelectric registration of interferogram, the modified software FastInterf to wave front restoring using inrterferograms with polisher teeth.

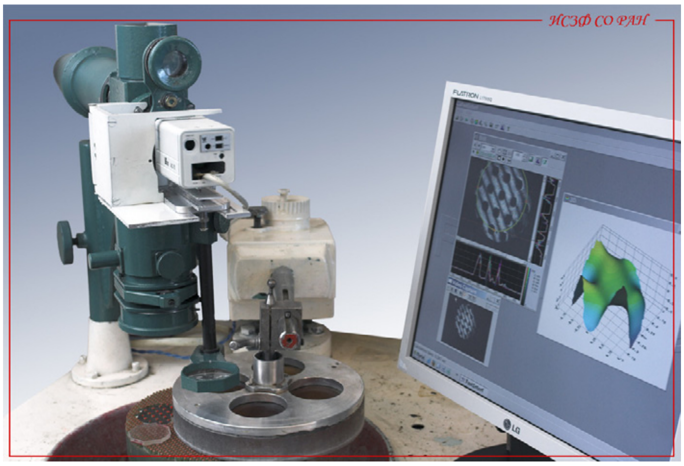

Figure 6. Device for finishing BF crystal plates. (The plate is removed from the separator and is shown on the polisher in front of the mirror).

The scheme of registering the wave front birefringence interferograms (like considered before) and the visualization of the plate parameters during the finishing are shown in Figure 7. The crystal wedge of the interferometer is installed in parallel beam between the crossed polarizers P1 and P2. The orientations of the polarizers transmission plane and the plates crystal axes are shown with arrows. Light passes twice though the wedge – when falling on the mirror at when reflecting from it. Because of the path- difference of the ordinary and extraordinary beams near eight interference fringes of the equal retardation appear in the wedge. The processed and reference plates are introduced in turn by separator for control into the zone of the interferometer at the stopped polisher. The crystal axes of the plates are oriented parallel the wedge axis. Since the reference plate is optically equal-thickness then the number, straightness and orientation of fringes at the combination with the wedge will be the same as those in the only wedge, but in general case their position is shifted in parallel if the plate thickness is not divisible by the interference integer order of for the wavelength of 6328 Å. The curvature of the fringes and their orientation in the interferogram of the processed plate depend on the shape of its surfaces, value and wedge direction, as well as on the crystal optical homogeneity.

On the computer there can be displayed the following information required for the control of the optical polishing process: the interferogram with applied aperture mask; three-dimensional surface for which the Y-direction position and the shape corresponds to the optical thickness; the table of the basic parameters characterizing the process of approaching to the reference plate in thickness.

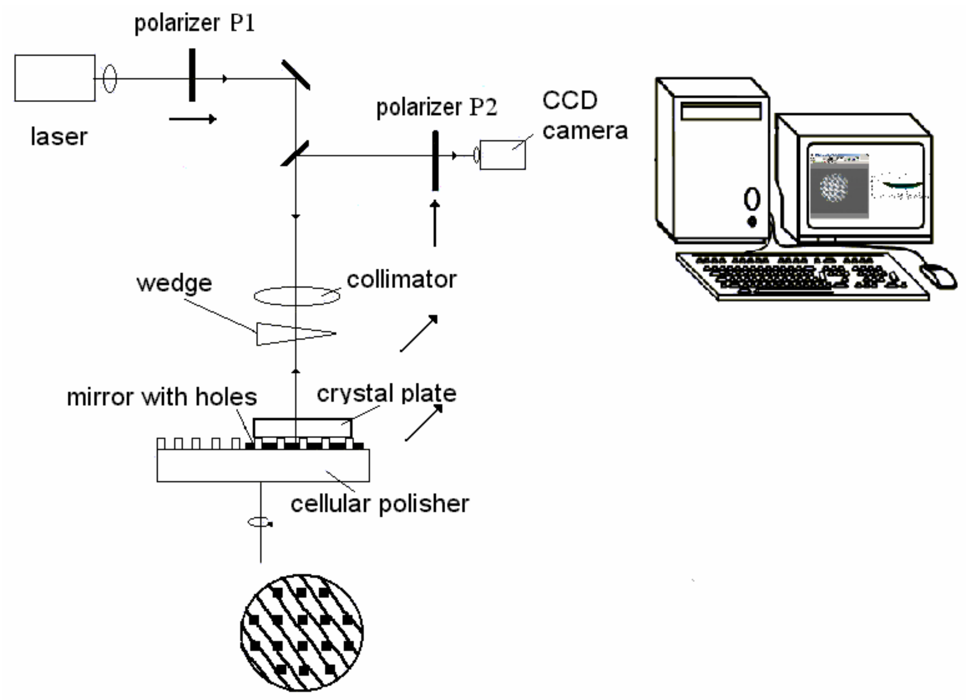

Figure 7. The scheme of control and registration of the interferograms.

The Fast Inter program calculates the wave front of the adjusted plate relative to the reference one. The "constant" parameter which is the relative parallel fringes shift in the processed plate characterizes the thickness allowance (in fractions of the interference order or λ). The parameters of optical wedge "tilt" and of the wedge azimuth "angle" are calculated according to change of the fringes number and orientation. At each time for the purpose of the regular control the polisher is installed under the interferometer in such a way that the polishing cells (teeth) of the mirror repeat definitely their position. In this case the aperture mask stored to the computer memory is the same during the whole finishing process.

There is illustrated the process of finishing of the calcite crystal plate of diameter 42 mm and thickness 10 mm (Figure 8,9). The wedge was removed and the thickness was adjusted relative to the reference plate. At the beginning of the process the plate had the thickness allowance of about 0.7 of the interference fringe (1.26 μm) and the wedge was of 0.08 of the fringe. The rate of the thickness change on the cellular polisher is usually in the range of 0.01–0.005 of the fringe in minute. The "more quiet" regime is chosen when approaching the given thickness.

The changes of the optical thickness and wedge are shown in figures according to calculated "constant" and "tilt" parameters of the interferometric measurements processed by the FastInterf program. The value of parameter in fractions of the interference order of retardant relative to the reference plate is indicated along the Y axis.

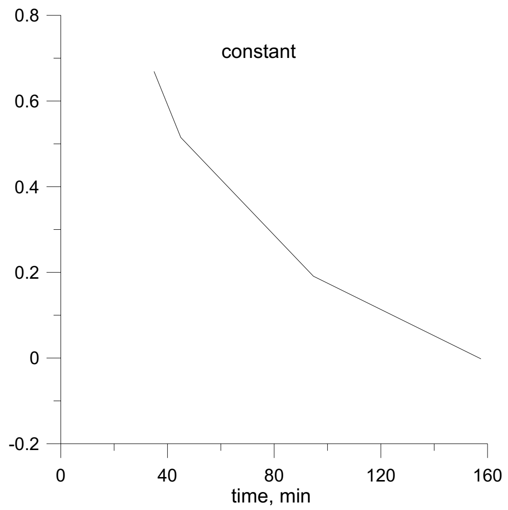

Figure 8. “Constant” parameter changing during the finishing.

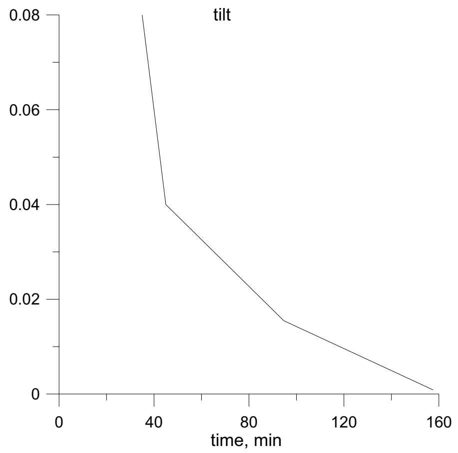

Figure 9. “Tilt” parameter variation during the finishing process.

The wave fronts corresponding to three final interferometric measurements of birefringence, are shown on Figure 14. The wave front reflects the shape of two surfaces of the plate under treatment. The final parameters of the plate are in tolerances, but one can see that flatness of surface has been spoiled on final stage of treatment a little bit.

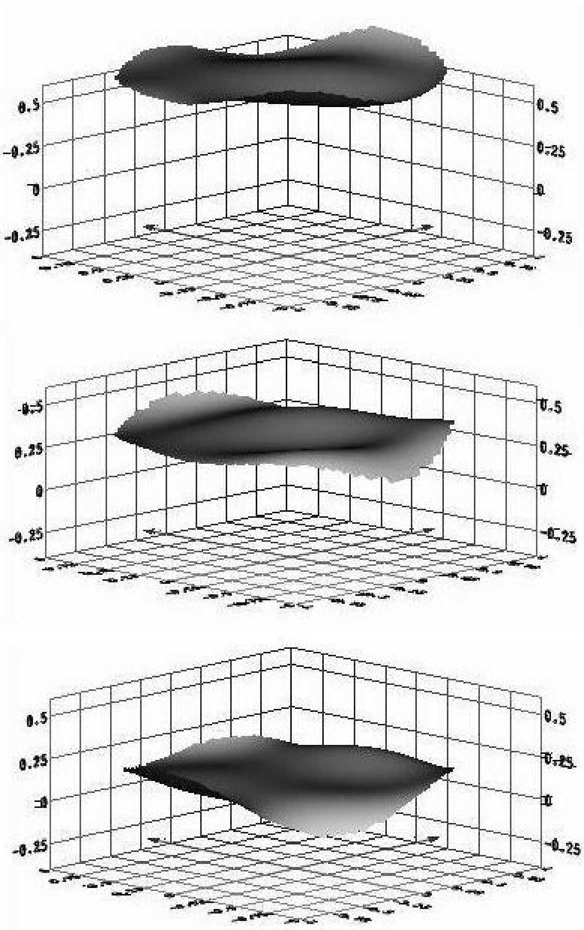

Figure 10. 3D maps of wave front at 45th, 95th и 155th minutes of treatment.

7. Conclusion

Manufacture of unique precise details in optical industry generally carries out particularly. Many parameters exerted influence on polishing process defy an engineering description, therefore it is difficult to set unambiguously the working conditions of optical machine. The feedback between technological interference control which shows the result of optical treatment, and machining conditions of polishing is realized to automatize manufacture. It should be the next stage of our work.

Acknowledgements

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