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MESO-OPTICAL FOURIER TRANSFORM MICROSCOPE WITH DOUBLE FOCUSING

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1. INTRODUCTION

The meso-optical Fourier transform microscope (MFTM) described in the earlier papers [1,2,3] is designed for fast searching for particle tracks in nuclear emulsion with known orientation and dip angles. In the system [1] the meso-optical mirror with ring response produces two meso-optical images of the particle track which are on the opposite sides of the focal ring. The focusing of the diffracted light is taking place only in the meridional section along the radial coordinate. In the sagittal section of the MFTM there is no focusing at all and as was explaned in [4] MFTM in the sagittal section can be considered as one dimensional «pin-hole» camera. It was also shown in [4] that the length of the meso-optical images in the sagittal section of the system [1] is equal to the diameter of the field of view of the MFTM. This property of the MFTM with single focusing enables one to localize spatially the end of the straight line particle track in the field of view of the MFTM.

The first prototype of the MFTM with double focusing which has been studied in [5] contains a single cylindrical lens to accomplish the focusing along the radial coordinate. The focusing along the angular coordinate in the sagittal section of the MFTM is produced by the Fourier transform lens. The meso-optical images of the particle tracks have the form of blurred spots. The double focusing gives the amelioration of the signal-to-noise ratio but needs one sacrifice — the observation could now be accomplished only in a small part of the orientation angles. The main drawback of the first prototype of the MFTM with double focusing [5] was a very small aperture of the single cylindrical lens used in these experiments: 1:30. Due to this the expected resolution along the radial coordinate was only 15 μm. The main obstacle for increasing of this feature of the system were spherical and coma aberrations of the single cylindrical lens.

To remove this drawback of the first prototype of the MFTM with double focusing we made a special objective with two cylindrical lenses to suppress the spherical and coma aberrations.

In this paper we describe in detail the MFTM with double focusing. It is shown experimentally that this device enables one to get extremely high concentration of information about the position of the particle track in the nuclear emulsion layer and thus to increase the signal-to-noise ratio. It is shown that sagittal spreading of the meso-optical images of the particle track can be eliminated completely in the frame of the diffraction limit. The performance of our new system is presented. The comparison of the MFTM with double focusing and Fourier transform microscope of the direct observation [6] has been made.

2. FIRST PROTOTYPE OF THE MFTM WITH DOUBLE FOCUSING

The first prototype of the MFTM with double focusing has been tested experimentally in 1987 [5]. This device was oriented to particle tracks with small spread of their orientation angles and with negligible multiple scattering. For such objects we use only small part of the focal ring and an arc of the central focal circle can be replaced by the tangent. Instead of meso-optical mirror with ring response having toroidal working surface we can use simple cylindrical lens. This transformation of the MFTM design also suits for the case of searching for particle tracks with known orientation angle. For this aim the rotable platforms with two-arm optical interface [1] was transformed into the rotating folk of the MFTM with one-channel photodetectors [8]. By means of this rotating folk we orient the searching for particle track with known orientation angle along symmetry axis of the illuminated region. The MFTM with double focusing must have the working angular interval of the order of $\pm 1^0$, as the estimated error of expected orientation angle of the searching for particle track being $\pm 1^0$.

Two experiments have been accomplished in paper [5]. In the first one the meso-optical element in the form of simple cylindrical lens was placed near the crossover of the convergent light beam. The length of the meso-optical images was defined by the diameter of the field of view of the MFTM and by the linear magnification of the cylindrical lens. In the second experiment [5,7] the focusing in the sagittal section was produced by means of the Fourier transform lens. The cylindrical lens gave the focusing in the meridional section of the microscope. Both focuses have been set in the common plane where the pick up system was placed. The resolution along the angular coordinate was determined by the width of the crossover of the convergent light beam, whereas in the first experiment the later was equal to MD, where M is the coefficient of linear magnification of the cylindrical lens, and D is the length of the field of view. The amelioration of the angular resolution was equal to 120:1.

The resolution along the radial coordinate was defined by the aperture of the cylindrical lens and the thread-off between the resolution and depth of the focus. In the prototype [5] we had $\Delta\rho \sim 15\ \mu$m.

The main drawback of the design [5] was the spherical aberrations of the simple cylindrical lens. To remove this drawback we have made cylindrical objective with two cylindrical lenses which minimize the spherical and coma aberrations.

3. MFTM WITH DOUBLE FOCUSING

Schematic diagram of the meso-optical Fourier transform microscope (MFTM) with double focusing is shown in Fig.1. The convergent light beam has an astigmatic structure: the focus in the meridional section is in the median plane of the nuclear emulsion layer 1, and the focus in the sagittal section is in the plane where the pick up matrix of the read out CCD TV-camera is mounted. The distance between the center of the CCD matrix and the optical axis of the system is R. The distance between nuclear emulsion layer and Fourier transform plane is H. The width of the illuminated region was equal to d = 36 μm, and the length $D \approx 3.0$ mm.

The diffracted light is transformed by the cylindrical objective 2 into the meso-optical image which is picked up by CCD TV camera 4. The concentration of the diffracted light into images spots was so high that we use neutral absorber filter 3.

The cylindrical objective of our device was constructed as a projected system of two components with fixed distance to the object l_1 = 32 mm, and to the pick up matrix of the CCD TV-camera, l_2 = 128 mm. The linear magnification of this system was M= 4:1. The calculations were made according to the recommendations [10] to suppress the spherical and coma aberrations. The expected resolution of the system is equal to 2 μm.

The ray paths of the diffracted light in the MFTM with double focusing is shown in Fig.2 for sagittal section and for meridional section.

Typical view of the monitor screen of the CCD TV-camera with meso-optical image of the neon nuclei in one arm of the device is presented

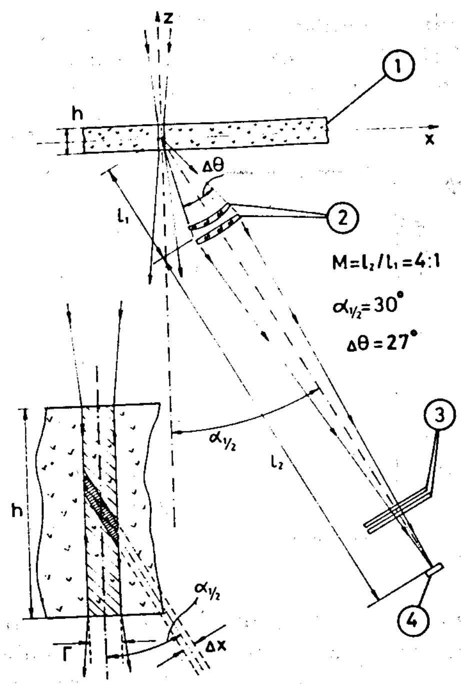


Fig.1. Schematic diagram of the meso-optical Fourier transform microscope (MFTM) with double focusing: 1 — nuclear emulsion layer, 2 — cylindrical objective, 3 — neutral absorber of the light; 4 — CCD-matrix of the TV-camera. Below to the left — section of the nuclear emulsion layer: single hatched region is the illuminated volume, double hatched region is the part of the illuminated volume which sees one pixel

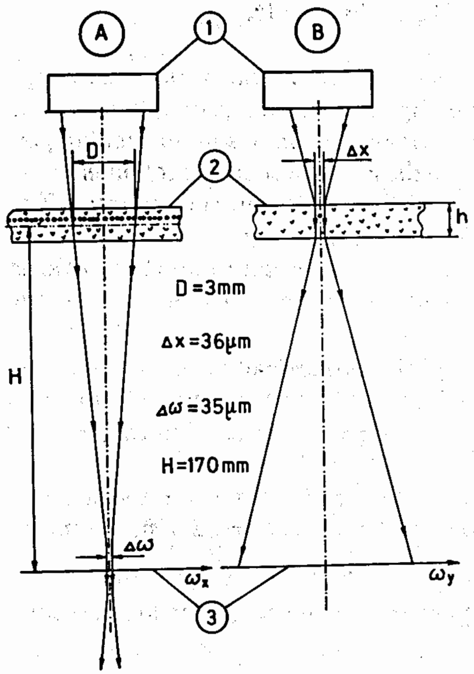
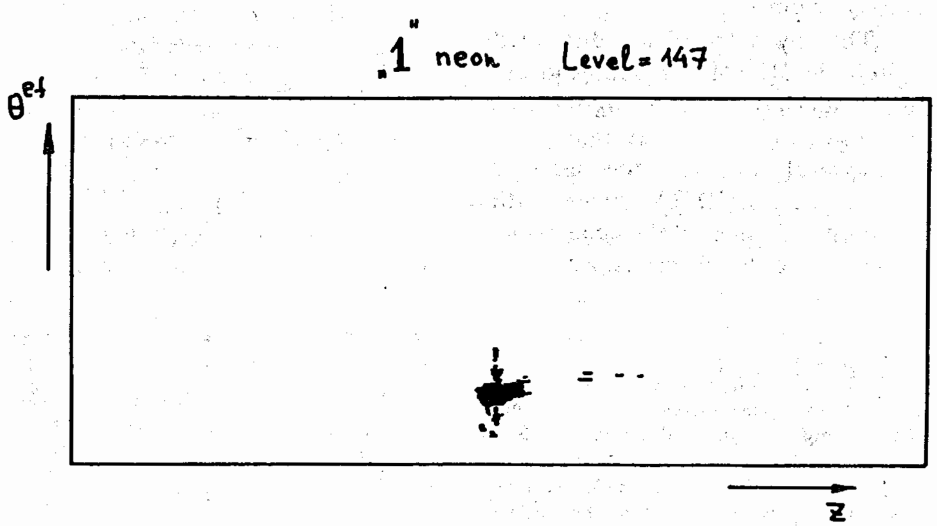


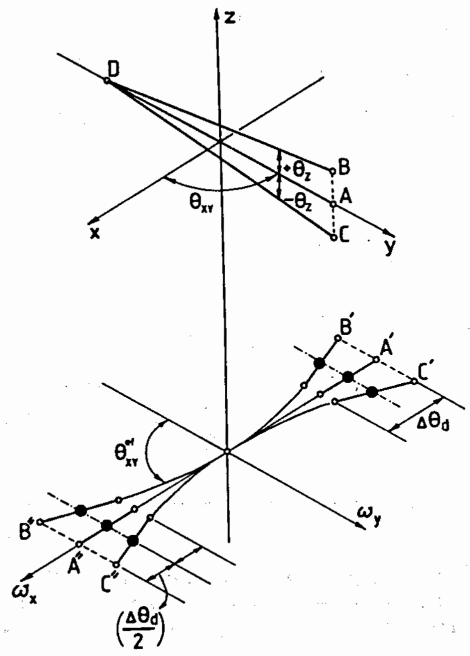
Fig.2. Ray paths in the MFTM with double focusing: 1 — convergent light beam, 2 — nuclear emulsion layer, 3 — cylindrical objective, 4 — pick up CCD-matrix of TV-camera: "A" — in the sagittal cross section, "B" — in the meridional cross section

Fig.3. Typical view of the meso-optical image of the particle track with high ionization level (neon nuclei) on the monitor screen of the CCD TV-camera: Z — depth coordinate, θ^{ef}_{xy} — effective orientation angle



in Fig.3. The fact that in our experiments we could pick up only one meso-optical image instead of two in both arms of the MFTM with double focusing produces principal ambiguities in the interpretation of the output data. To explain this

Fig.4. The expected position of the meso-optical image of the particle track with known orientation angle θ_{xy} and dip angle θ_z. Only one arm of the device is used



problem we show on Fig.4 the expected position of the meso-optical image along the angular coordinate of the particle track with known orientation angle θ_{xy} and dip angle θ_z. Only one arm of the device is shown in Fig.4.

As was explained in [1] four geometrical parameters which define the position of the particle track in 3D-space (θ_{xy}, θ_z, ρ_0, Z_o) can be estimated in the MFTM with one common CCD-matrix which picks up the data both in the left and in the right arms of the MFTM without any mechanical displacement of the object or MFTM. In general case the position of two meso-optical images in the frame of the CCD-martix is defined not only by the orientation angle θ_{xy} but also by the angle φ between two meso-optical images [1]. For the real design of the MFTM [9] we have

$$\sin \varphi = tg\, \theta_z\, tg\, \alpha_{1/2}, \qquad (1)$$

where $\alpha_{1/2}$ is the angle between the central and side optical axes of the MFTM. In the experiments described in this paper $\alpha_{1/2} = 30°$ and

$$\varphi = 0.58\, \theta_z. \qquad (2)$$

Thus the effective orientation angle

$$\theta^{ef}_{xy} = \theta_{xy} \pm 0.58\, \theta_z. \qquad (3)$$

This two-fold ambiguity of our results can be removed only by means of the system with two arms and with one common matrix of the CCD TV-camera.

4. EXPERIMENTS

The test experiments with one arm MFTM of double focusing were accomplished for particle tracks of neon nuclei from «1» to «8» and of shower particle

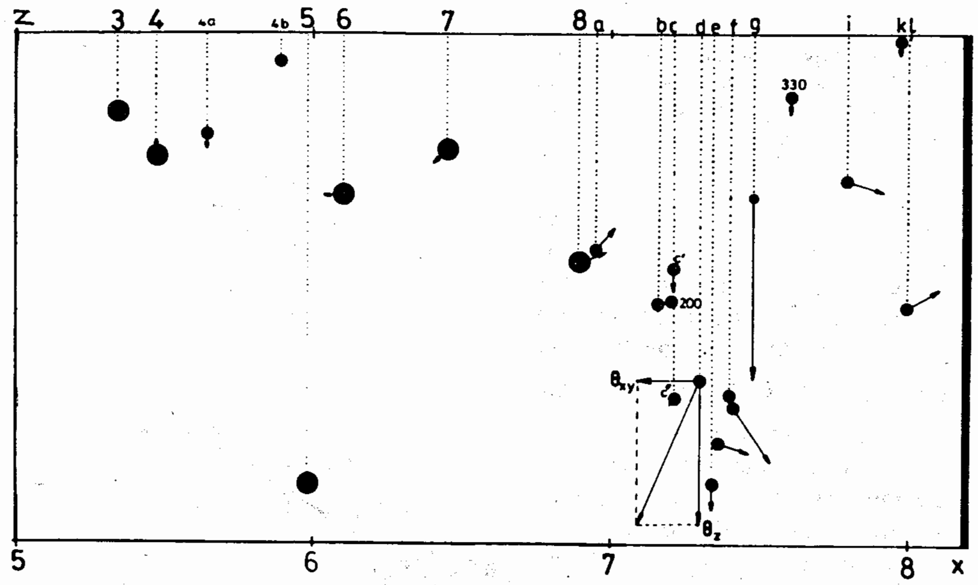


Fig.5. The object of the test measurements: particle tracks of high ionization level (neon nuclei) "3"—"8" and the shower particles tracks a, b, ... Four parameters of each particle track are depicted: transversal coordinate X, depth coordinate Z, orientation angle θ_{xy} and dip angle θ_z

tracks which are lying to the right from the particle track «8». The positions of these particle tracks, the orientation angle θ_{xy} and the dip angle θ_z measured by the manual system with ordinary microscope are given in Fig.5.

The results of the measurements of Z-coordinate of these particle tracks made by MFTM with double focusing are shown in Fig.6. The depth of the nuclear emulsion layer $h = 200$ μm can be decomposed into 33 pixels of CCD-matrix. We see the nonhorizontal position of the nuclear emulsion layer which produces an angle ~ 1° with horizontal plane of the system.

The results of the measurements accomplished automatically by the computer are presented in Fig.7 in the form of 3D-plot with four parameters: effective orientation angle θ_{xy}^{ef}, transversal (radial) coordinate X, effective depth coordinate Z and the intensity of the meso-optical signal I. The measure of the later was a diameter of the ball on the top of the Z-segment. We must conclude from Fig.7, that the $c'c''$-doublet of the parallel particle tracks is not resolved into two components. The cause of this is the computer program which can distinguish two spots on the screen of the computer monitor when they have large mutual distances. The same effect we see in Fig.8 where the intensity of the signal as a numbe of pixels in the spot S is presented as a function of the coordinate X for comparator level 190. From Fig.8 we may conclude that the width

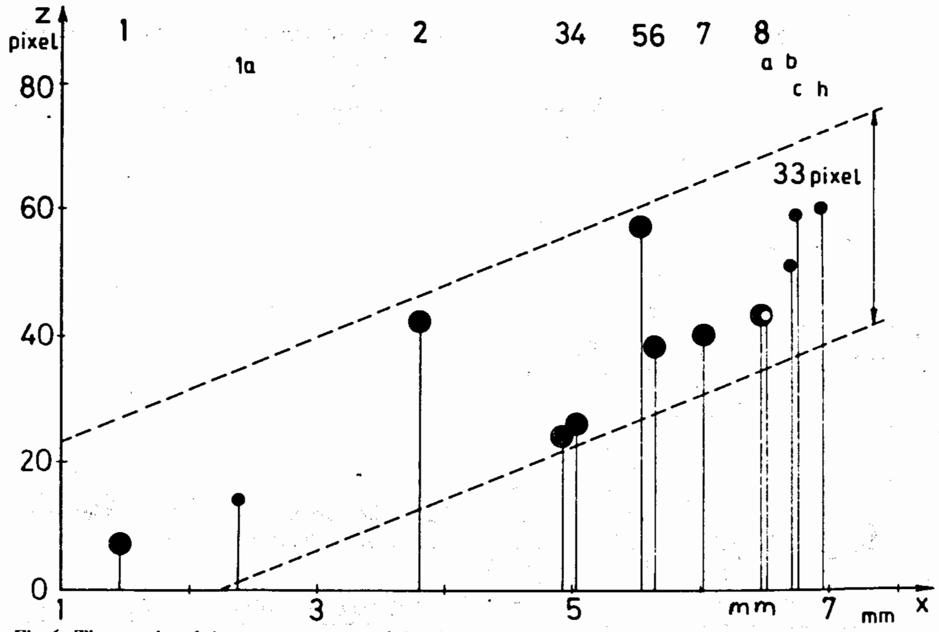


Fig.6. The results of the measurements of the depth coordinate Z of the object particle tracks: 1 pixel corresponds to 6 μm of Z-axiz

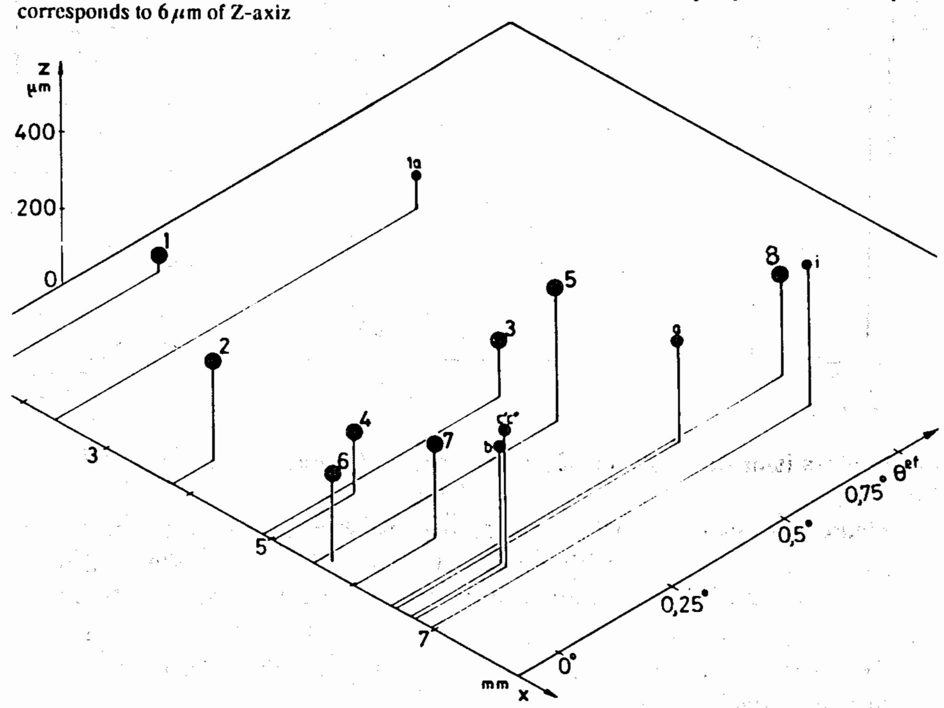


Fig.7. 3D-plot with four parameters (see text)

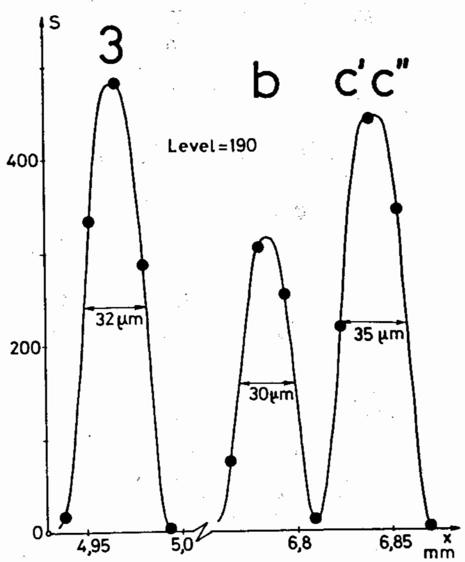


Fig.8. The transverse coordinate discrimination curve for particle tracks "b", "$c'c''$" and for neon nuclei "3". The width of the picks is equal to the width of the illuminated region

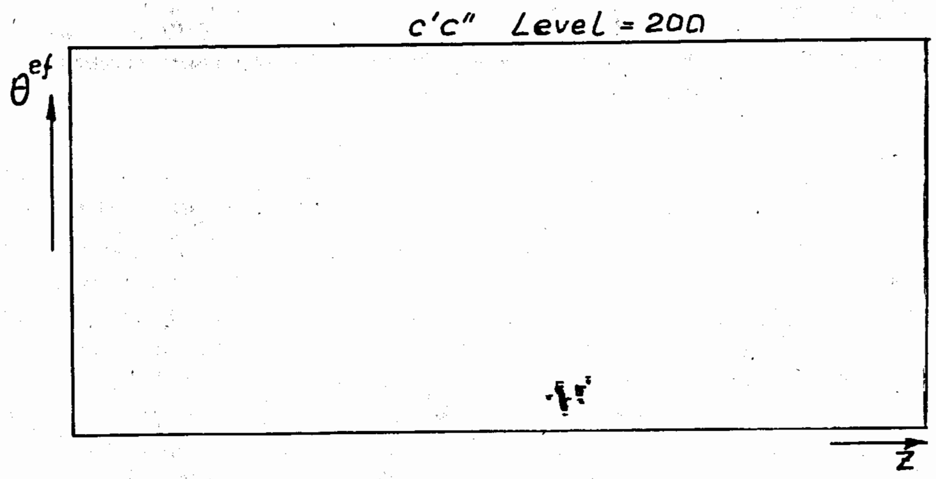


Fig.9. The view of the resolved $c'c''$-doublet on the screen of the computer monitor

of the picks is of the order of 32 μm, but the $c'c''$-doublet is unresolved as in Fig.7.

Meanwhile the $c'c''$-doublet is indeed a resolved one on the screen of the computer monitor (Fig.9) with horizontal axis as a Z-coordinate and with vertical axis as an θ^{ef}_{xy}-coordinate. The comparator level was equal to 200 when the noise corresponded to comparator level 150.

The two resolved peaks of $c'c''$-doublet are shown in Fig.10 in another scale for the same axes X and θ^{ef}_{xy}.

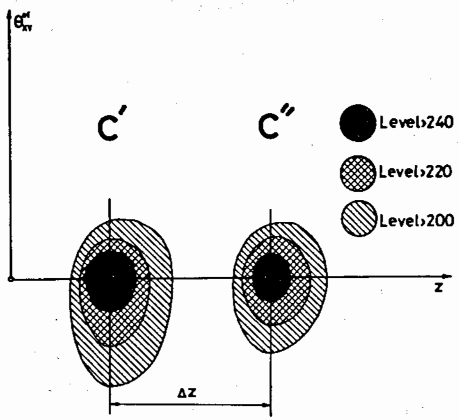


Fig.10. The resolved peaks of $c'c''$-doublet in the coordinate frame Z, θ^{ef}_{xy}

The cross section of the $c'c''$-doublet along Z-axis is shown in Fig.11. We see that two peaks c' and c'' are well resolved for mutual depth distance $\Delta Z = 60$ μm. The resolution of the system can be estimated as $\delta Z = \pm$ 15 μm. One pixel of CCD-matrix corresponds to 10 μm along Z-axis.

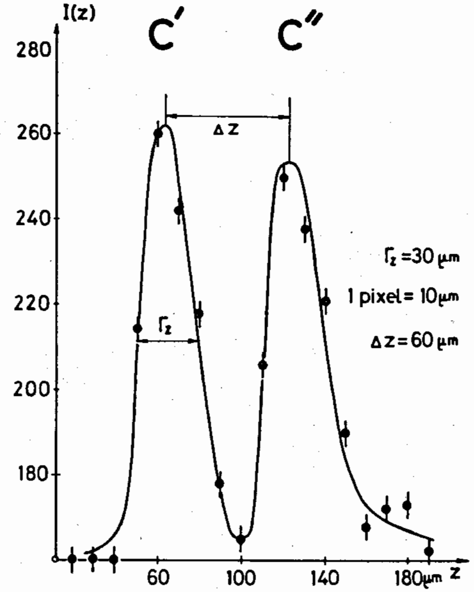


Fig.11. The cross section of the $c'c''$-doublet along Z-coordinate (see text)

The cross section of the particle track c' along θ^{ef}_{xy}-axis is given in Fig.12. We see that angular resolution $\delta\theta^{ef}_{xy} = \pm$ 1.2'. One pixel of the CCD-matrix corresponds to 0.54' angular minute.

It is instructive to present the results of the longitudinal manual tracing along the particle track «f» with 40 grains per 100 μm shown in Fig.5. The results are given in Fig.12 as 3D-plot with X- and Y-coordinates of the moving stage of the MFTM with attached rotating folk and with intensity signal $\sqrt{S}$ as a third

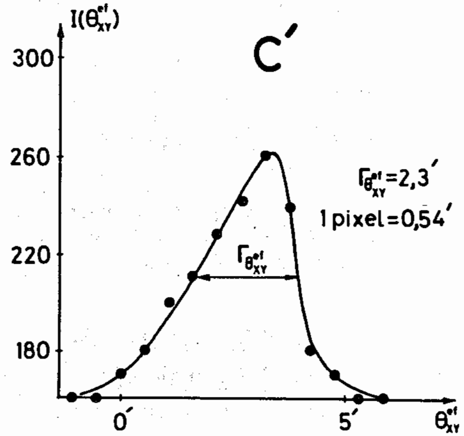


Fig.12. The cross section of the particle track c' along θ^{ef}_{xy} coordinate

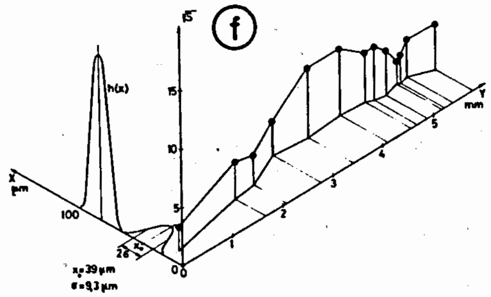


Fig.13. Longitudinal tracing of the particle track «f» (see text)

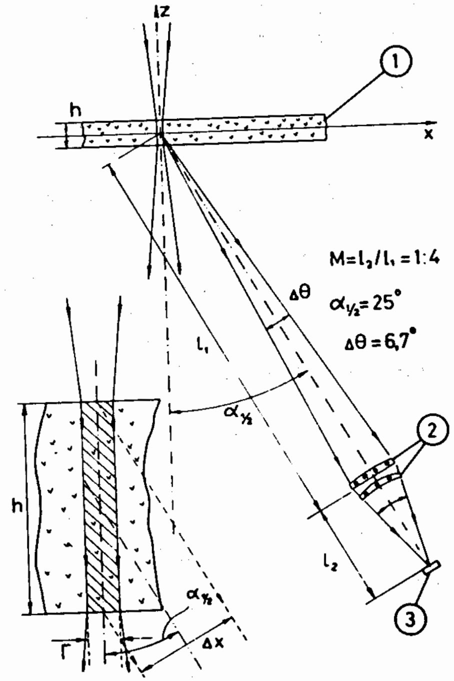


Fig.14. Inverse geometry of the observation which is equivalent to the Fourier transform microscope of the direct observation

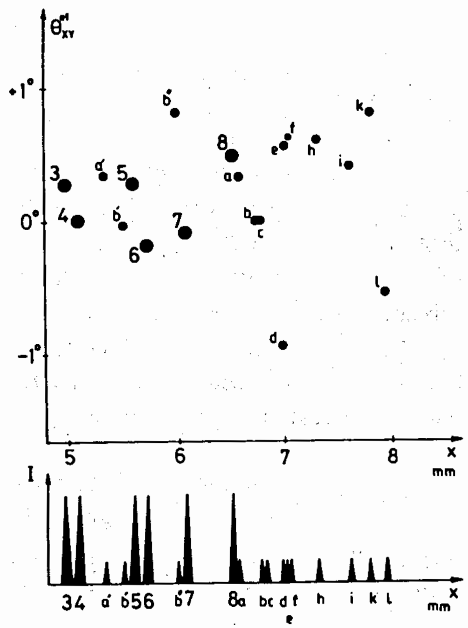


Fig.15. 2D-plot of the results which were received in the inverse geometry of the observation

coordinate. We see that the expected resolution curve h(x) and the standard dispersion $\sigma = 9.3$ μm along X-axis are in good agreement.

To make the equivalent comparison of the MFTM with double focusing and the Fourier transform microscope of the direct observation we accomplish the control experiment with inverse position of the cylindrical objective as shown in Fig.14. The linear magnification of the cylindrical objective was equal in this

configuration to $M_2 = 0.25$ instead of $M_1 = 4.0$ in the main experiments. The resolution along Z-coordinate was equal to $\Delta Z \sim 150\,\mu$m and we cannot discriminate the particle tracks with different Z-coordinates. The results of these mesurements with inverse geometry can be presented now in the form of 2D-plot (Fig.15).

5. CONCLUSION

The properties of the MFTM with double focusing were tested experimentally. It was proved that the information about the particle track in nuclear emulsion can be concentrated in one spot in the plane of the CCD-matrix of the TV-camera. The dimensions of this spot are of the order of 2·3 pixels.

The analogous concentration of the information were observed in the MFTM with single focusing [1] but the dimension of the corresponding spot along angular coordinate was equal to the length of the field of view of the MFTM. In our system with double focusing the corresponding dimension of the spot has been changed from 2.7 mm to 40 μm or 60 times smaller than in the previous system [1].

The angular resolution of the MFTM with double focusing can be estimated as $\delta\theta = 1.3'$ and the resolution along the depth coordinate Z as $\delta Z = 10\,\mu$m. This gives 20 additional degrees of freedom along Z-coordinate in comparison to the Fourier transform microscope of the direct observation. The noise is suppressed in the same proportion. The system with two arms will have $\delta Z \approx 7\,\mu$m and $\delta X \approx 7\,\mu$m.

REFERENCES

1. Astakhov A.Ya. et al. — Nucl. Instr. and Meth., 1989, A283, p.13—23.
2. Soroko L.M. — Nucl. Tracks Radiat. Meas., 1991, 19, p.267—700.
3. Soroko L.M. — Nucl. Tracks Radiat. Meas., 1991, 18, p.391—402.
4. Soroko L.M. — JINR Commun. P13-87-527, Dubna, 1987 (in Russian).
5. Soroko L.M. — JINR Commun. P13-87-468, Dubna, 1987 (in Russian).
6. Batusov Yu.A. et al. — JINR Commun. E13-91-427, Dubna, 1991.
7. Soroko L.M. — Progress in Optics (ed. E.Wolf), Elsevier, Amsterdam, 1989, 27, p.109—160.
8. Astakhov A.Ya. et al. — JINR Commun. P13-91-299, Dubna, 1991 (in Russian).
9. Soroko L.M., Tereshchenko V.V. — JINR Commun 13-91-204, Dubna, 1991 (in Russian).
10. Slyusarev G.G. — Methody rascheta opticheskikh sistem, Mashinostroenie, Leningrad, 1969, p.350, Equations VI.21 and VI.22.

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