сообщения
объединенного
института
ядерных
исследований
дубна

E13-87-387

Gy.L.Bencze, L.M.Soroko

BASIC PARAMETERS OF THE MESOOPTICAL FOURIER TRANSFORM MICROSCOPE FOR NUCLEAR RESEARCH EMULSION

1987

1. INTRODUCTION

The Mesooptical Fourier Transform Microscope (MFTM) is a specialized device the purpose of which is to observe selectively straight line particle tracks in a track nuclear emulsion layer. In the previous papers [1–10] the idea of the MFTM [1], the principle of operation [2–4], the first experimental set-up [5] and the first experimental results [6], the analysis of the optical system and some new experiments with the improved set-up [7], the processing algorithms of the signals from the MFTM [8,9], and the imaging properties of the MFTM [10] are described.

In this paper we treat theoretically the basic parameters of the MFTM. In § 2 the accuracy of measurements and the speed of operation of the MFTM are discussed. The effect of a limited number of silver grains in the straight line particle track on the output signals of the MFTM is investigated in § 3. In § 4 the signal-to-noise ratio, the resolution and the depth of focus problem are treated.

2. THE ACCURACY OF MEASUREMENTS AND THE SPEED OF OPERATION OF THE MFTM

As has been shown in [7,10] the segment of the straight line particle track which is in the field of view of the MFTM is transformed by the MFTM into two output signals in the exit plane of the MFTM. These signals appear on the opposite sides of the focal ring and on the straight line which is perpendicular to the direction of the measured particle track. Each output signal has a nearly oval form. Its length in the radial direction equals [10]

$$\Delta\rho = \lambda / \alpha_{1/2}, \qquad (1)$$

where λ is the wave length of light, and $2\alpha_{1/2}$ is the total angular aperture of the mesooptical imaging system. The length of the output signal in the angular direction $\Delta \ell_\theta$ equals [10]

$$\Delta \ell_\theta = MD, \qquad (2)$$

where M is the linear magnification of the mesooptical imaging system and D is the diameter of the field of view of the MFTM.

The locus of the output signals is a narrow focal ring of the mean radius R and width MD. The distance between the centre of the output signal and the focal circle of the radius R is equal to the displacement of the particle track with respect to the centre of the field of view of the MFTM.

The information displayed in the focal ring of the MFTM can be read out by a proper photoelectric system with light sensitive elements of the sizes $\Delta\rho$ and $\Delta\ell_\theta$. The position of the measured particle track in the radial direction can be estimated with the accuracy $\Delta\rho$ while the angular accuracy $\Delta\theta$ is equal to /10/

$$\Delta\theta = \Delta\ell_\theta / \pi R . \qquad (3)$$

In the experimental set-up of the MFTM described in /6/ R = = 80 mm, D = 600 μm, M = 1, λ = 0,633 μm, and $a_{1/4}$ = 1/8. Thus the accuracy of measurement in the MFTM is given by $\Delta\rho \cong 5$ μm and $\Delta\theta \cong 8'$ and enables us to find the events /9/ with high confidence.

Now let us estimate the speed of operation of the MFTM. Comparing the full area of the focal ring equal to $2\pi RDM$ with the area of one readout element we get the total number of information elements

$$N_t = N_\rho \cdot N_\theta = \frac{2\pi RDM}{\Delta\rho \cdot \Delta\ell_\theta} = \frac{2DM}{\Delta\rho \cdot \Delta\theta}, \qquad (4)$$

where N_ρ and N_θ are the numbers of information elements in ρ and θ - directions respectively. For the experimental set-up of the MFTM mentioned above we have $N_\rho \approx 120$, $N_\theta \approx 3000$ and thus $N_t \approx 3{,}6\cdot 10^5$.

Let us suppose that the output signals are detected by a charge coupled device (CCD) matrix with the number of sensitive elements 200x300 and with movies frequency of 25 frames/sec. Leaving the problem of gathering the output signals over the focal ring unsettled and taking into account that in the MFTM there is no need in deep scanning we can estimate the total readout time for the given field of view as 1 sec. This speed of operation is considerably higher than that of the traditional optical microscope equipped with a computerized image analyser /11/, to say nothing of manual searching.

Finally, it is worth noting that conditions of some physical experiments permit us to read out the output signals over the angular range which is smaller than 360°. For example in the neutrino experiments conducted at the accelerator FNAL (USA) particle tracks of relativistic ionization are lying inside a $\pm 15°$ angular interval. Similar experiments carried out at the synchrotron of the Institute of High Energy Physics (USSR), have given an angular interval of $\pm 45°$. In these cases the readout time needed for the MFTM is proportionally reduced.

3. THE EFFECT OF THE LIMITED NUMBER OF SILVER GRAINS IN THE PARTICLE TRACK ON THE OUTPUT SIGNAL

The influence of the grain structure of the straight line particle tracks on the output signals of the MFTM has been treated in /2/ . By computer modelling it has been shown that existence of gaps in the particle track gives rise to the additional diffraction components outside the main diffraction picture and to a background spread over a number of angular elements. It has also been shown that for a particle track consisting of 30 silver grains over 100 μm length the signal-to-noise ratio is 20:1. These results have been supplemented by investigations presented here.

To explain the structure of the output signals in the case of a straight line particle track consisting of a limited number of dot-like silver grains, we refer to Figs. 1-3. As has been shown in /10/ , a dot-like input object forms a circle in the exit plane of the MFTM. This output signal formed by a single silver grain is shown rather roughly in Fig. 1. Since the MFTM is a space-invariant optical system /10/, the output images of two silver grains separated by a distance of ℓ give two circles the centres of which are separated by a distance of $M\ell$ (Fig. 2). The output signals given by four silver grains are shown in Fig. 3. The pair of output signals appear at the area of intersection of the circles, while other parts of circles give a comparatively low background spread over the whole focal ring.

To get some quantitative estimations of the light intensity distributions in the Fourier plane (x_2, y_2) of the MFTM /7,10/ for a particle track directed along the axis Oy_1 and consisting of different numbers of silver grains n we have performed computer modelling. As has been shown in /7/ , this light intensity distribution has a quasi 1D-character with very weak dependence on the x_2-coordinate. The light intensity distri-

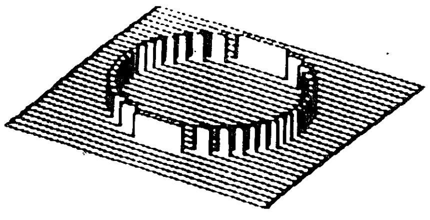

Fig. 1. 3D-plot of 2D-light intensity distribution at the exit plane of the MFTM for an object with only one silver grain.

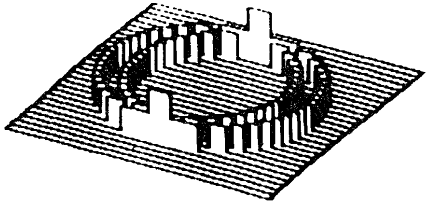

Fig. 2. 3D-plot of 2D-light intensity distribution at the exit plane of the MFTM for an object of two silver grains.

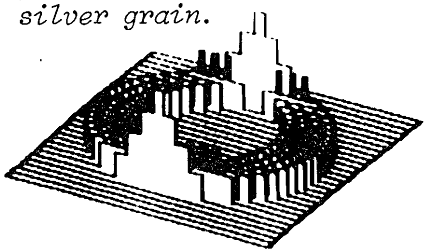

Fig. 3. 3D-plot of 2D-light intensity distribution at the exit plane of the MFTM for a particle track of four silver grains.

bution along the y_2-axis,however,strongly depends on the number of silver grains.Some typical examples are presented in Figs.4-6.In Fig.4-a the field of view of the MFTM with only two silver grains is shown.The picture of the light intensity distribution is shown in Fig.4-b and the exact distribution of light intensity is presented in Fig. 4-c. The analogous pictures for a particle track with n = 22 and n = 100 are given in Figs. 5 and 6.

As has been shown in /7,10/ , the light diffracted by a gray particle track directed along the y_1-axis is concentrated in the Fourier plane along the x_2-axis within the $|y_2| < \lambda d_{12}/D$ wide main diffraction maximum where d_{12} is the distance between the input and the Fourier planes /7/ . The energy of light within this region has been calculated for different numbers of silver grains and for various statistical realizations of silver grain distributions in the particle track. The results of calculations have shown that the energy of light concentrated within the area of the main maximum hardly depends on realization of the silver grain distribution, and

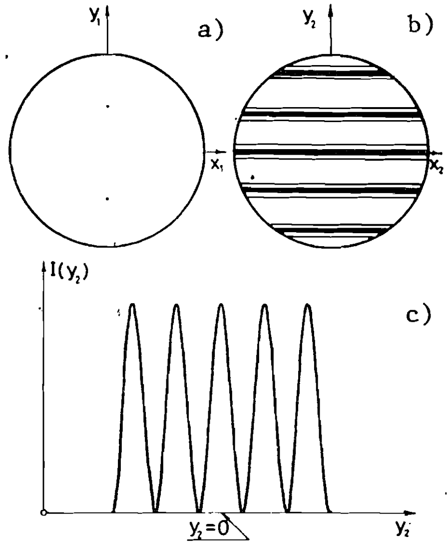

Fig. 4. a) The object plane (x_1, y_1) with two silver grains. b) The picture of the light intensity distribution for this object in the Fourier plane (x_2, y_2) of the MFTM. c) The curve of the light intensity distribution versus y_2 at $x_2 = 0$.

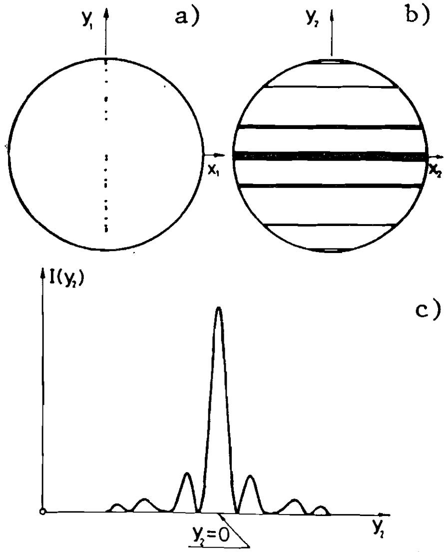

Fig. 5 a, b, c. The same pictures as in Fig. 4 a,b,c, but for a particle track with 22 silver grains.

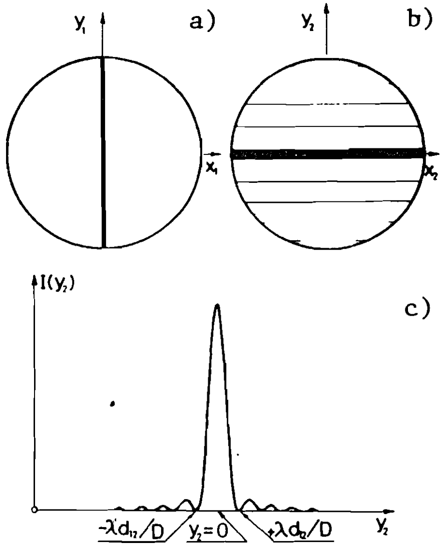

Fig. 6 a, b, c. The same pictures as in Fig.4 a,b,c, but for a gray particle track as an object.

the dependence on the number of grains can be simply approximated by the following formula:

$$\frac{I_o(n)}{I_t(n)} = \frac{n}{N_D}, \qquad n \le N_D. \tag{5}$$

where I_t is the total energy of light, I_o is the part of this energy which is lying within the area of the main maximum $|y_2| < \lambda d_{12}/D$, N_D is the number of silver grains for which the particle track can be considered as a gray one. For $n = N_D$ the correct ratio $I_o/I_t = 0{,}903$ instead of 1,0 given by Eq. (5). This difference shows the approximation error of Eq. (5).

4. SIGNAL-TO-NOISE RATIO, RESOLUTION AND DEPTH OF FOCUS IN MFMT

Let us treat the signal-to-noise ratio in the MFTM. The light intensity diffracted by one silver grain is proportional to a_o^2, where a_o is the diameter of the silver grain. Neglecting the proportionality factor of the order of unity the total intensity of light I_t diffracted by n silver grains can be simply written as

$$I_t(n) = n a_o^2. \tag{6}$$

As two output signals of the MFTM are formed by the light energy concentrated in the main maximum each of the output signals has the intensity I_S equal to

$$I_S = \frac{I_o}{2} = \frac{n I_t(n)}{2N_D} = \frac{n^2 a_o^2}{2N_D}. \tag{7}$$

Now let us suppose that the background formed by silver grains is randomly distributed over the nuclear emulsion layer and that the only source of the fluctuation of this background is the Poisson-noise. Let N_B be the number of background silver grains inside the field of view of the MFTM. The total intensity of this background uniformly distributed over the focal ring is equal to $N_B \cdot a_o^2$. Therefore the background intensity of light fallen into one element of the readout photoelectric device I_B is

$$I_B = N_B a_o^2 \frac{\Delta \ell_\theta \, \Delta \rho}{2\pi RDM}. \tag{8}$$

Taking into account Eqs. 7, 8, 3, 4 and the fact that $D = a_o \cdot N_D$ we can obtain the following expression for the signal-to-noise ratio of the MFTM:

$$\frac{I_S}{I_B} = \frac{\pi n^2 a_o \alpha_{1/2} R}{N_B \lambda D}. \tag{9}$$

From Eq. (9) we can see that when the radius of the focal circle R increases or the number of silver grains in the particle track get greater, the signal-to-noise ratio proportionally increases. When the diameter of the field of view D increases, the signal-to-noise ratio decreases proportionally to 1/D, as the number of silver grains n in the particle track increases linearly; while that of the noise silver grains N_B, quadratically, so the relation n^2/N_B remains constant.

As an example we can refer to the MFTM described in /5/. Its parameters are given in §2. For particle tracks with typical parameters $n = 20$ silver grains over 100 μm and $a_o \simeq 1\,\mu$m we get for the signal-to-noise ratio the following relation:

$$I_S/I_B \simeq 10^7/N_B. \tag{10}$$

From Eq. (9) we can also derive the fundamental conclusion. In typical conditions of nuclear emulsion searching the signal from the straight line particle track of relativistic ionization with $a_o < 1\,\mu$m and small n can be registered by meso-optical system having angular aperture $\alpha_{1/2} \ll 1$. This is rather paradoxal in terms of traditional optics, but it follows directly from the imaging properties of the MFTM. This conclusion is of very high importance for the solution of the depth of focus problem. As is well known, the depth of focus is proportional to $(\alpha_{1/2})^{-2}$ and in the case of $\alpha_{1/2} = 1/8$ the depth of focus reaches 200-300 μm that is the thickness of the nuclear emulsion used in the scientific program "Neutrino detector" /12/.

The authors wish to thank S.A.Bunjatov for his continuous interest and support and Yu.A.Batusov for useful discussions of this paper.

REFERENCES

1. Soroko L.M. JINR, Б1-13-81-229, Dubna, 1981.
2. Lyucov V.V., Soroko L.M. JINR, Б1-13-81-312, Dubna, 1981.
3. Soroko L.M. JINR, Б1-10-82-808, Dubna, 1982.
4. Soroko L.M. JINR, Б1-10-82-809, Dubna, 1982.
5. Astakhov A.Ya. et al. JINR, P13-83-119, Dubna, 1983.
6. Astakhov A.Ya., Soroko L.M. JINR, P13-83-120, Dubna, 1983.
7. Astakhov A.Ya. et al. JINR, P13-84-277, Dubna, 1984.
8. Bencze Gy.L., Soroko L.M. JINR, E13-84-310, Dubna, 1984.
9. Bencze Gy.L., Soroko L.M. JINR, P13-85.136, Dubna, 1985.
10. Bencze Gy.L., Soroko L.M. JINR, P13-85-137, Dubna, 1985.
11. CERN Courier, 1983, June, 5, p.184.
12. JINR, D1,2,13-84-332, Dubna, 1984.

Received by Publishing Department
on June 5, 1987.

Бенце Д., Сороко Л.М. E13-87-387

Основные параметры мезооптического фурье-микроскопа для ядерной фотоэмульсии

Дан теоретический анализ основных параметров мезооптического фурье-микроскопа /МФМ/ для ядерной фотоэмульсии: точность измерения, разрешение, отношение сигнала к шуму, глубина фокуса и быстродействие МФМ. Приведены преимущества МФМ над традиционным оптическим микроскопом.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1987

Bencze Gy.L., Soroko L.M. E13-87-387

Basic Parameters of the Mesooptical Fourier Transform Microscope for Nuclear Research Emulsion

The basic parameters of the Mesooptical Fourier Transform Microscope (MFTM) for nuclear research emulsion, namely, the accuracy of measurements, the resolution, the signal-to-noise ratio, the depth of focus and the speed of operation are treated theoretically. The advantages of the MFTM over the traditional optical microscope are presented.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1987