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CONFOCAL SCANNER FOR VERTICAL PARTICLE TRACKS IN THE NUCLEAR PHOTOEMULSION

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Конфокальный сканер для вертикальных следов частиц
в ядерной фотоэмульсии

Дано описание конфокального сканера, предназначенного для селективного наблюдения вертикальных следов частиц в ядерной фотоэмульсии. Искомый след частицы изображается под углом 45° к оптической оси системы. Конфокальный сканер имеет новый оптический элемент — «ортогонализатор изображения», при помощи которого протяженное изображение наклонного вертикального следа частицы поворачивается на угол 90°. Приводится также стереоскопическая версия конфокального сканера. Описанные системы будут использованы в экспериментах по исследованию осцилляций нейтрино в ускорительных экспериментах.

Работа выполнена в Лаборатории ядерных проблем им. В. П. Джелепова ОИЯИ.

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Confocal Scanner for Vertical Particle Tracks
in the Nuclear Photoemulsion

A confocal scanner for selective observation of the vertical particle tracks in the nuclear photoemulsion is described. The particle track being searched for is imaging at an angle of 45° with respect to the optical axis of the system. The confocal scanner is provided with a new optical element, an «image orthogonalizator», by means of which the extended image of the inclined vertical particle track is rotated over an angle of 90°. The stereoscopic version of the confocal scanner is presented as well. The described systems will be used in the experiments for investigation of the neutrino oscillations in the accelerators experiments.

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

Preprint of the Joint Institute for Nuclear Research. Dubna, 2005

INTRODUCTION

The first meso-optical microscope for selective observation of the vertical particle tracks in the nuclear photoemulsion was described in [1]. The scanning operation along depth coordinate has been completely eliminated in this microscope.

To suppress the noise from side-lobes of the light diffraction, a confocal meso-optical microscope has been proposed [2]. Its illuminating zone had the form of narrow «fens» oriented parallel to the optical axis of the system. The productivity of this microscope was estimated to be 10^2 times higher than that in the traditional optical microscope with z-scanning operation. To ameliorate the signal-to-noise ratio of this microscope there were proposed some new variants of the meso-optical condenser [3].

The principle of the dark-field confocal scanning microscope for selective observation of the vertical particle tracks in the nuclear photoemulsion was described in [4]. The construction of this microscope, build on the basis of the two-dimensional measurement microscope, has been presented. The experimental testing of this microscope has been made at high surface density of the vertical particle tracks in the nuclear photoemulsion. The dark-field images of the vertical particle tracks are seen as bright signals on the dark background.

The depth of the photoemulsion layer was equal to $200\,\mu\mathrm{m}$, the width of the illuminating zone was equal to $6\,\mu\mathrm{m}$, and the transfer dimension of the illuminating volume was equal to $250\,\mu\mathrm{m}$.

The results of the experimental testing are shown in Fig. 1 for microobjective $\times 8.0/0.16$. The signals of four vertical particles tracks are shown as dark spots on the white background. These signals were calculated from the information, presented in [4] in the numerical form. The signal-to-noise ratio was equal to $52:1$.

Meanwhile the observed in the experiment [4] vertical particle tracks were oriented at the angle $\theta = 8.5^\circ$ with respect to the vertical axis of the system. So the real vertical particle tracks were illuminated partially only over the length of $40\,\mu\mathrm{m}$ instead of $200\,\mu\mathrm{m}$. On taking into account this fact we may estimate the signal-to-noise ratio for «pure» vertical particle tracks as $250:1$.

By rejecting the cliche of the universal stereotypic approaches to the imaging of the objects, it was found, that the confocal scanner described in this paper, does suit extremely well to see very narrow class of objects such as practically parallel vertical particle tracks in the nuclear photoemulsion with small number of silver grains (< 20).

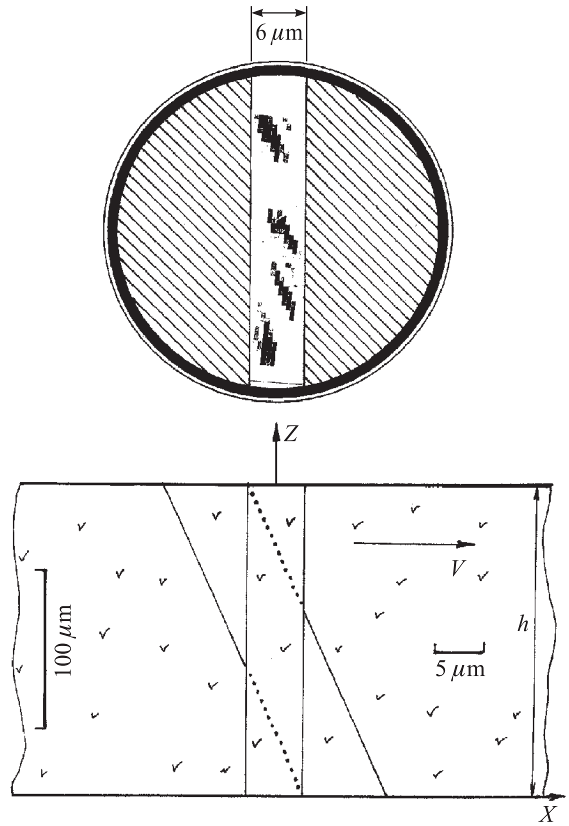

Fig. 1. The results of the experimental testing of the dark-field confocal scanning microscope for selective observation of the vertical particle tracks. Top: signals of four particle tracks inside the illuminating zone of 6 μm width. Bottom: the cross section of the same region

The confocal scanner is provided with new optical element, «image orthogonalizator», which accomplishes the rotation of the extended image of the inclined vertical particle track, produced by the conventional lens, over the angle of 90°.

Due to this our confocal scanner has no depth scanning device and in spite of this it sees in focus the whole vertical particle track which was inclined at the angle of 45° with respect to the optical axis of the system.

Our confocal scanner has no imaging microobjective, no system of z-scanning, no CCD (charge-coupled device) pick-up system and no computer with its correlation programs for searching of the real vertical particle track in the nuclear photoemulsion. Instead of this our confocal scanner is provided with pick-up device, which generates one-dimensional signal of time. The stereoscopic version of the confocal scanner is described in this paper as well.

1. CONFOCAL SCANNER FOR VERTICAL PARTICLE TRACKS IN THE NUCLEAR PHOTOEMULSION

The principal scheme of the confocal scanner is shown in Fig. 2. The main feature of this confocal scanner is that the vertical particle track, going along

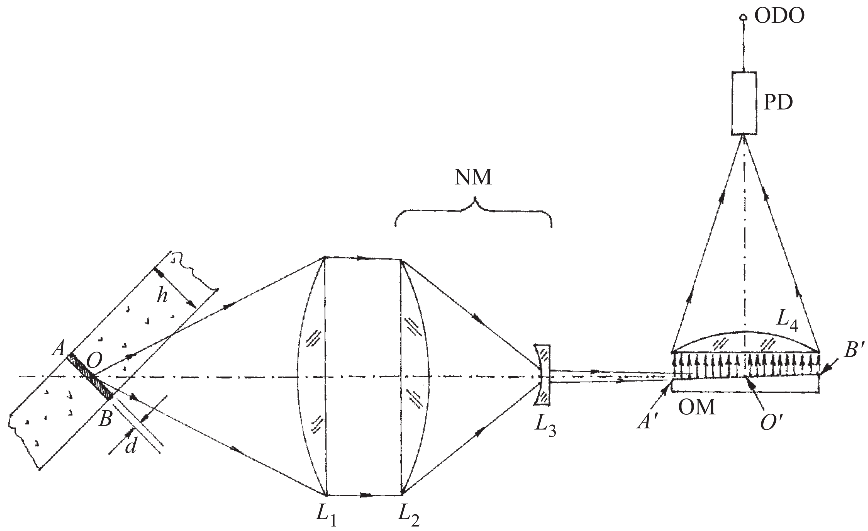

Fig. 2. The principal scheme of the confocal scanner for vertical particle tracks: L_1 — main imaging lens, L_2 and L_3 — lenses of the Newton monocular, L_4 — collecting lens, OM — orthogonalization mirror, PhD — point-like photodiode; A', O' and B' are the imaging points of A, O and B points of the vertical particle track, d — width of the illuminating zone, $\sim 2\,\mu\mathrm{m}$

optical axis of the whole system, is oriented at the angle of 45° with respect to the axis of the imaging system. Due to this we can see simultaneously all elements of this vertical particle track. The optical system is provided with one conventional positive lens, which accomplishes in fact a central projection of very small object volume. The focus length of this lens is equal to $16\,\mathrm{mm}$, that is much larger than in the traditional micro-objective of the optical microscope.

The imaging of the particle track, oriented at the angle of $45°$ with respect to the optical axis, creates extremely complex problems. Namely, the length of the extended image, produced by such a system, will be equal to

$$\Delta\ell_2 = \Delta\ell_1 \cdot M^2, \tag{1}$$

where M is the linear magnification of the lens L_1. For $M = 20$ we have $\Delta\ell_2 = 80\,\mathrm{mm}$. So we cannot see in focus simultaneously the extended image of inclined vertical particle track.

In our confocal scanner this problem has been resolved by means of new optical element, «image orthogonalizator», shown in Fig. 3. Each element of the

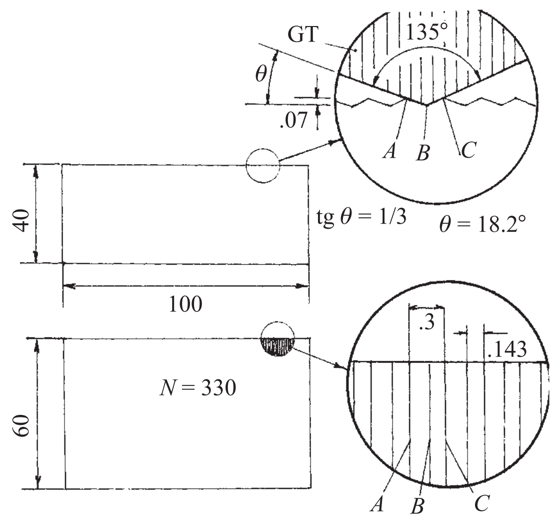

Fig. 3. Image orthogonalization system: GT — grooving tool; A, B and C are three points of the lamelar region, BC is the working part of the lamelar mirror. All dimensions — in mm

extended image over the length of 80 mm is rotated as a whole by this optical element over the angle of 90°. As this rotation is accomplished at all elements of the extended image, we do see simultaneously all elements of the vertical particle track in focus.

The calculations and the results of direct measurements have shown that the focus of the imaging parts of the inclined particle track produces a pure plane without any sagging, if the linear magnification M of the lens L_1 will be more than 10.

After this rotation operation we collect the light from all parts of the extended image of the inclined vertical particle track by means of the positive lens L_4 and direct it into the point-like photodiode PhD. Thus we get one-dimensional signal of time at the output of the confocal scanner.

The distance from the lens L_1 to the central part of the extended image of the vertical particle track is equal to

$$\ell_2 = M \cdot f. \tag{2}$$

For $f = 16\,\mathrm{mm}$ and $M = 20$ we have $\ell_2 \approx (300 \pm 40)\,\mathrm{mm}$. To reduce the distance ℓ_2, we use Newton monocular with two lenses L_2 and L_3.

2. ON-LINE DIFFERENTIATION OF THE OUTPUT SIGNALS

To increase the signal-to-noise ratio in the confocal scanner, we accomplish on-line differentiation of the output signals. So we detect the differences

$$f(t_n) - f(t_{n-1}) = \Delta f(n). \tag{3}$$

This on-line operation increases the signal-to-noise ratio in k times, where

$$k \approx \sqrt{N} \tag{4}$$

and N is the total number of the noise silver grains inside the illuminating zone. So, for $N \sim 100$, we get $k \approx 10$.

3. STEREOSCOPIC CONFOCAL SCANNER FOR VERTICAL PARTICLE TRACKS

A stereoscopic version of the confocal scanner can in principal additionally increase the signal-to-noise ratio. In this version, we observe two images of the same vertical particle track along two stereoscopic axes (Fig. 4).

Along the left stereoscopic axis, L, we see the vertical particle track, inclined at the angle (–45°), and along the right stereoscopic axis, R, we see the same vertical particle track, inclined at the angle (+45°) with respect to the central axis.

In the stereoscopic version of the confocal scanner we have two «image orthogonalizators». So we send two output signals after the time differentiations into the AND electronic coincidence as shown in Fig. 5.

4. PRODUCTIVITY OF THE CONFOCAL SCANNER

Now let us estimate the productivity of our confocal scanner, which works as a wide-row drill. We suppose that the resulting signal-to-noise ratio, increased by the methods, described above, allows one to take the wide scanning zone of the width of 2 mm. So the number of the nonstop scanning of the plate $50{\times}50$ mm^2 will be equal to 25. Each passage with linear velocity of 10 mm/s will last 5 s. The total working passage time of the whole plate will be equal to 125 s. On accounting for the free-running time we can accomplish the whole scanning for about 180 s.

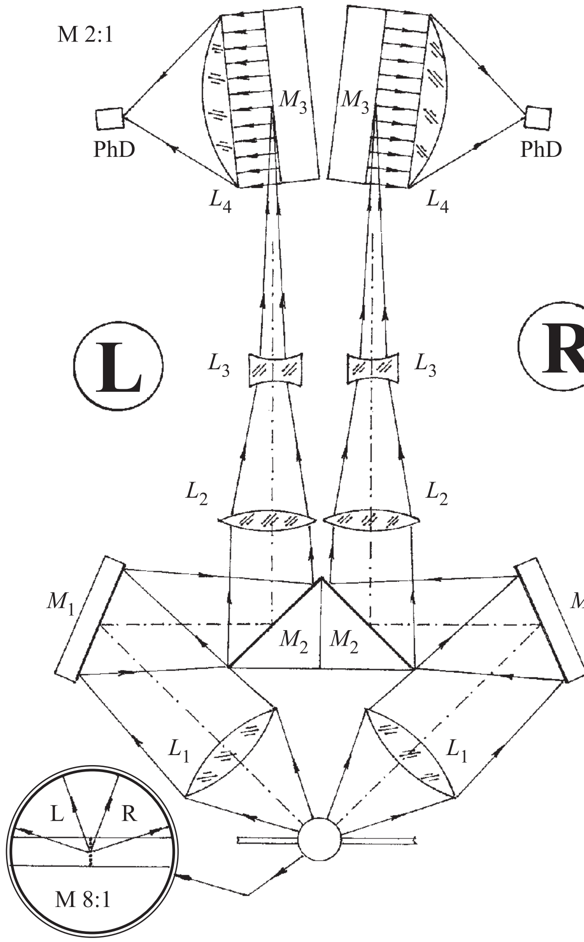

Fig. 4. Stereoscopic confocal scanner for the vertical particle tracks, provided with two confocal scanners on both sides of view (L and R): L_1 — two main imaging lenses, L_2 and L_3 — two pair of Newton monocular lenses, L_4 — two collecting lenses, M_1 — two first-plane mirrors, M_2 — two second-plane mirrors, M_3 — two orthogonalization mirrors, PhD — two point-like photodiodes

To get the complete information about the vertical particle tracks we must accomplish the scanning of our plate twice: along x and along y axes. So we need for all scanning operations about 360 s $\approx 6\,\mathrm{min}$. The clock frequency of the electronic circuit for this rate will be equal to 10^4 Hz.

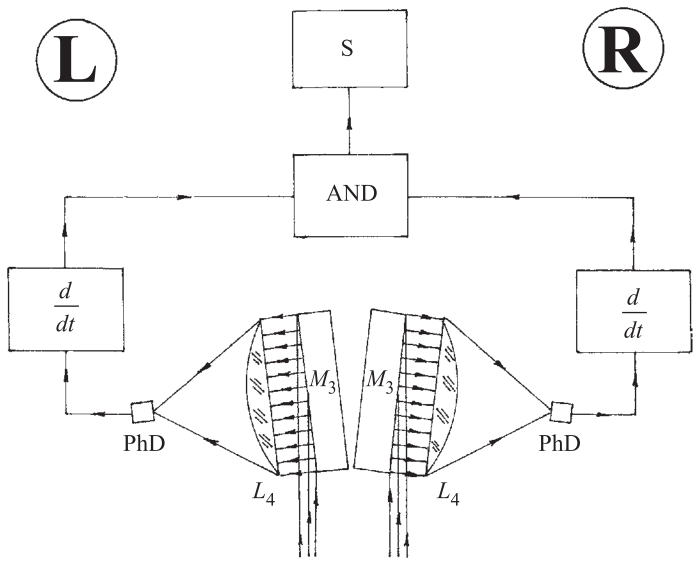

Fig. 5. Coincidence electronic circuit for two output signals from the stereoscopic confocal scanner for vertical particle tracks: M_3 — two orthogonalization mirrors, PhD — two point-like photodiodes, d/dt — time differentiation circuit, AND — coincidence electronic circuit, S — storage block

CONCLUSIONS

1. The vertical particle track, being searched for, is inclined at the angle of 45° with respect to the optical axis.

2. Our confocal scanner is equipped with new optical element, «image orthogonalizator», which rotates the extended image of the inclined vertical particle track over the angle of 90°.

3. It is shown that the focus of the imaging parts of the inclined particle track forms a plane without any sagging, if the linear magnification M of the main imaging lens L_1 is more than 10.

4. The signal at the output of the confocal scanner has the form of one-dimensional signal of time.

5. The on-line differentiation of this output signal increases the signal-to-noise ratio in $\sqrt{N}$ times, where N is the number of the noise silver grains inside the illuminating zone of $2\,\mu\text{m}$ width.

6. A stereoscopic version of the confocal scanner for vertical particle tracks is presented. In this system we observe two images of the same vertical particle track along two stereoscopic axes. The signal-to-noise ratio in the stereoscopic confocal scanner may be higher than in the mono-confocal scanner.

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