Milada Kopečná, Jan Kopečný*

The Second-Order Degree of Laser Beam Coherence Measurement

Numerical values obtained for the degree of spatial coherence of a He-Ne laser beam in various mode conditions are reported. The deviation from ideal coherence has been measured by means of the Mach-Zehnder interferometer and the modified Michelson stellar interferometer.

1. Introduction

The coherence of the laser beam is one of its most important qualities. Many studies on various aspects of coherence have been made [1], [2], [3]. In this paper, we wish to report some interesting results obtained by investigating spatial coherence of a He-Ne laser light.

Light coherence qualities are usually studied in connection with interference phenomena. In our experiments the degree of spatial coherence has been obtained by inspecting the visibility of interference fringes [4].

The coherence degree of light vibrations at two points P_1 and P_2 is a function of the coordinates of the points P_1 and P_2. The situation is illustrated in Fig. 1.

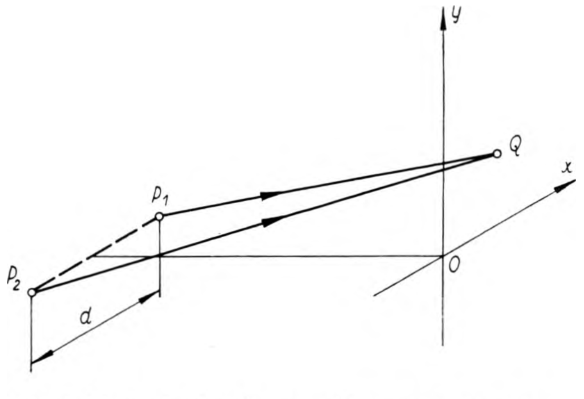

Fig. 1. Illustrating interference with two point sources

The modulus of the second-order degree of spatial coherence is given by [4]

$$|\gamma_{12}(0)| = \frac{I_{\max}-I_{\min}}{I_{\max}+I_{\min}} \, \frac{I_1+I_2}{2(I_1)^{\frac{1}{2}}(I_2)^{\frac{1}{2}}}, \qquad (1)$$

where $I_{\max}$ is the maximum intensity and $I_{\min}$ is an adjacent minimum of the interference pattern. I_1 is the intensity which would be obtained at the point of observation Q if the point P_1 alone were emitting light, I_2 is of a similar meaning.

When the light vibrations reach approximately the same intensity, equation (1) is reduced to

$$|\gamma_{12}(0)| = \frac{I_{\max}-I_{\min}}{I_{\max}+I_{\min}}. \qquad (2)$$

2. Experimental Set-up

Two experimental set-ups have been used. The first one was based on Mach-Zehnder interferometer [1]. Fig. 2a shows the Mach-Zehnder interferometer in the basic position with the mirrors M_3 and M_4 placed symmetricaly. Light entering the interferometer is divided in the semi-reflecting mirror M_1 into two beams which being reflected at mirrors M_3 and M_4 recombine at the second semi-reflecting mirror M_2 and interfere at the point of observation Q. In this case the beams emerging from the identical points $P_1 = P_2$ interfere at point Q. When the mirror M_3 is displaced in the marked direction (Fig. 3a) by the distance d, the interference pattern at point Q is formed by two beams emerging from the different points P_1, P_2 having the same separation d. Figures 2b and 3b show the cross-section of two beams in the sphere of observation with the shaded part denoting where interference arises.

---

*) Department of Physics, Vysoká škola báňská, Michálkovická 109, Ostrava, Czechoslovakia.

The arrangement of the experiment is shown in Fig. 4. The light from the laser source S is concentrated by the microscope objective L_1 on a black screen C with a pinhole which acts as a secondary source. Now the light is made parallel by a colimator objective L_2 and transverse the Mach–Zehnder interferometer. The lens L_3 forms an image of the secondary source. The interference pattern is enlarged by means of the lens L_4 and registered by photomultiplier PH with a very narrow slit in front of it. The slit is parallel to the fringes and is moved in the direction normal to the fringes. The outputting signal from the multiplier is used on the Y axis of a rectangular coordinate XY recorder R, while a signal proportional to the displacement of the slit is used on the X axis.

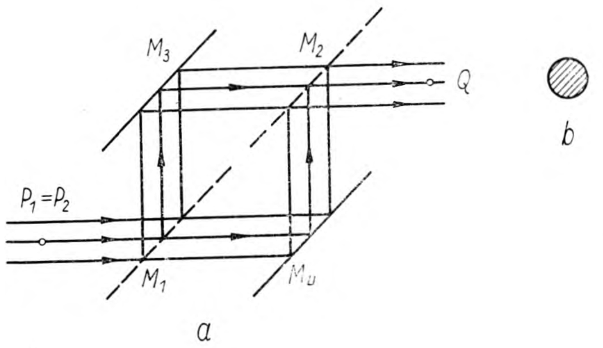

Fig. 2. Interference in the Mach–Zehnder interferometer a) interferometer with the mirrors M_3 and M_4 placed symmetrically, b) the cross-section of the interfering beams

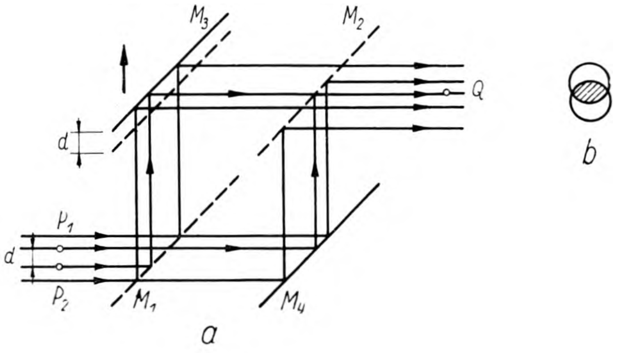

Fig. 3. Interference in the Mach–Zehnder interferometer a) interferometer with the mirror M_3 displaced by the distance d, b) the cross-section of the interfering beams

The second experimental set-up is based on the modified Michelson stellar interferometer [3]. Fig. 5 shows the measuring arrangement. The optical system with the exception of the interferometer — is the same as in the previous experiment. Parallel light beams are reflected by a prism H_1, two mirrors M_1 and M_2 and prism H_2; they traverse next the two identical apertures P', P'' with the fixed separation. The interference pattern forms again in the focal plane of the lens L_3. The distance d of the two beams traversing the apertures P' and P'' can be varied by moving the prism H_1 in the marked direction. This operation is equivalent to displacing the mirror M_3 in the Mach–Zehnder interferometer.

3. Experimental Results

The measurements of the second-order degree of spatial coherence of the He–Ne laser Meopta 2000K the confocal type operated at the wavelength $\lambda = 632.8$ nm have been made by means of the exper-

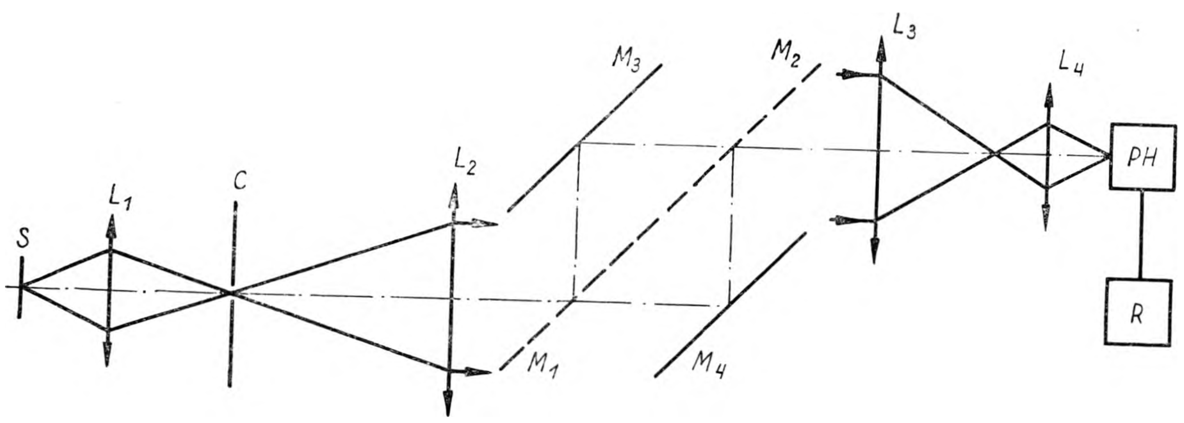

Fig. 4. Experimental arrangement for measuring the degree of coherence with the aid of the Mach–Zehnder interferometer

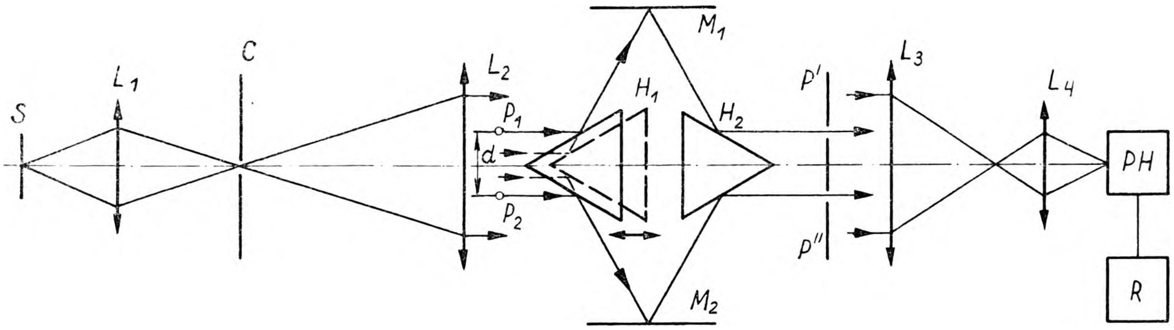

Fig. 5. Experimental arrangement for measuring the degree of coherence based on modified Michelson stellar interferometer

imental set-ups described above. The laser beam spatial coherence in various mode conditions has been measured by changing the distance d of the examined points P_1 and P_2 on the cross-section of the laser beam.

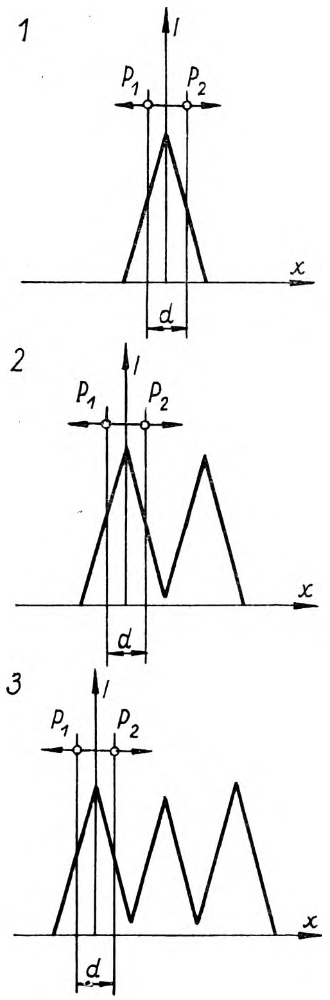

Fig. 6a. The schematic intensity distribution of the modes: *1* — TEM$_{00}$, *2* — TEM$_{10}$, *3* — TEM$_{20}$

Our measurements on spatial coherence in the modes TEM$_{00}$, TEM$_{10}$, TEM$_{20}$ verified the results of authors [1], [2], [3], provided that the investigated points P_1 and P_2 are chosen only from one spot of a mode. Fig. 6a shows the method of choosing points P_1 and P_2 which were moved equally along the indicated line from the centre C of the spot. The curves in Fig. 6b show the degree of spatial coherence for the modes TEM$_{00}$, TEM$_{10}$, TEM$_{20}$ as a function of relative distances $a = d/D$, where d is the distance of points P_1 and P_2 and D is the diameter of the mode.

Disagreement with expected results has appeared when points P_1 and P_2, chosen from different spots of the mode, have been investigated. Fig. 7b shows the results of measurements of the modes TEM$_{10}$,

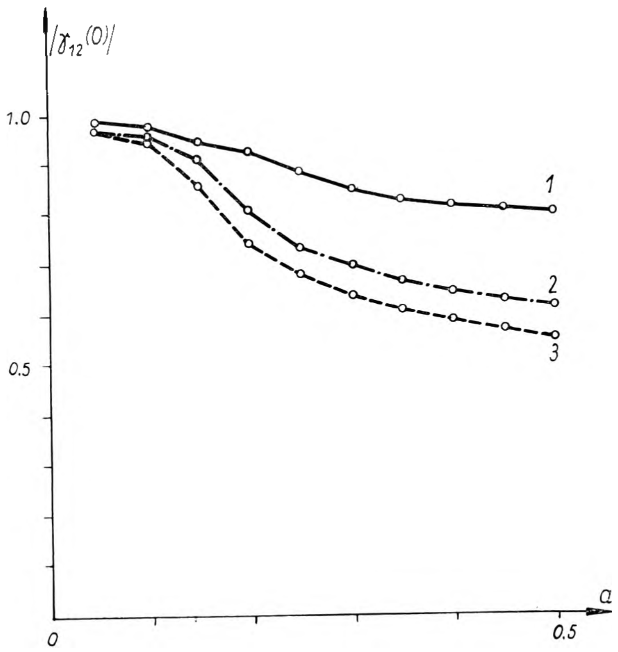

Fig. 6b. Degree of spatial coherence of a laser light. Curves *1*, *2*, *3* correspond to the modes TEM$_{00}$, TEM$_{10}$, TEM$_{20}$

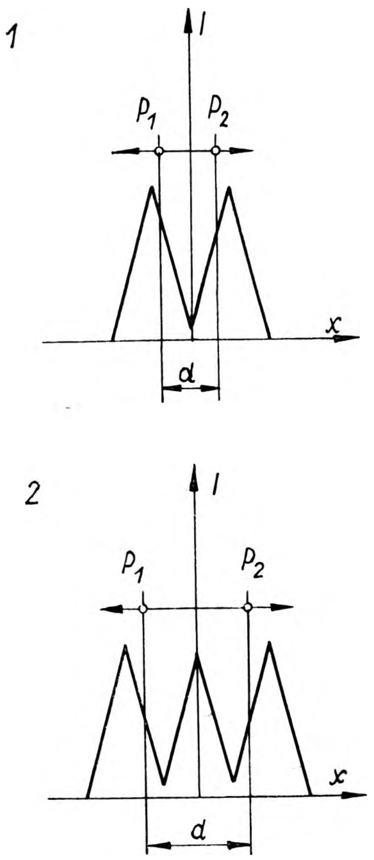

Fig. 7a. The schematic intensity distribution of the modes: *1* — TEM$_{10}$, *2* — TEM$_{20}$

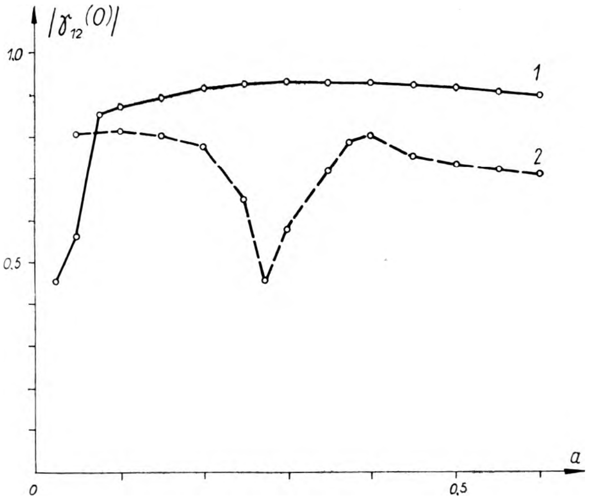

Fig. 7b. Degree of spatial coherence of a laser light. Curves *1,2* correspond to the modes TEM$_{10}$, TEM$_{20}$

TEM$_{20}$, where the points P_1 and P_2 have been examined in a manner shown in Fig. 7a.

Finally, the laser light spatial coherence emitted in complicated mode condition TEM$_{mn}$ has been measured. Interesting results — shown in Fig. 8b — have been obtained. The degree of spatial coherence was calculated from the results of measurements made on the two experimental set-ups.

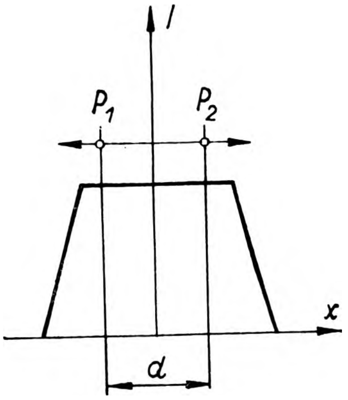

Fig. 8a. The schematic intensity distribution of the mode TEM$_{mn}$

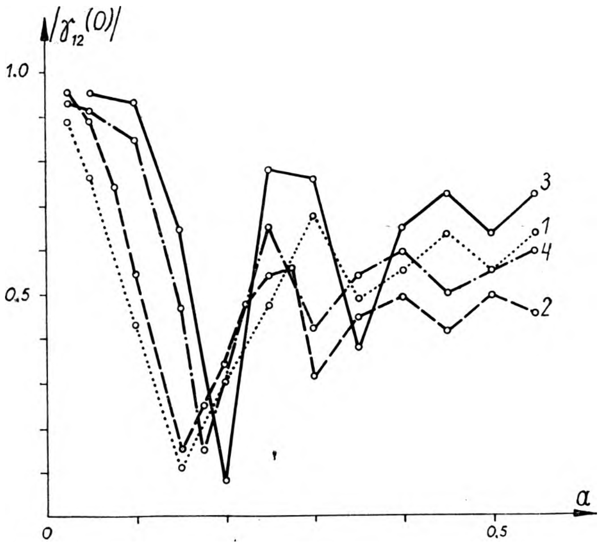

Fig. 8b. Degree of spatial coherence of a laser light for the mode TEM$_{mn}$.
Curves *1,2* were obtained by measuring on the Mach-Zehnder interferometer, curves *3,4* by a modified Michelson stellar interferometer

References

[1] JÁNOSSY M., CSILLAG L., KÁNTOR K., *The spatial coherence of a He-Ne laser operating at 1.15 μ, measured with a Mach-Zehnder interferometer*, Physics Letters, **18**, 2, 124, 1965.

[2] VALIGNAT S., ERBEIA A., *Coherence spatiale d'un faisceau laser*, Optics communications, **1**, 3, 135, 1969.

[3] ASAKURA T., FUJIWARA H., *Measurement of spatial coherence using modified Michelson stellar interferometer*, Optics Technology, **1**, 157, 1969.

[4] BORN M., WOLF E., Principles of Optics, Pergamon Press, Oxford 1965.