

DIAGNOSTICS OF THE THERMAL TRACK OF A POWERFUL LASER BEAM

S.P. Istomin and M.Yu. Sverdlov

Altai State University, Barnaul
Received September 5, 1989

The process of formation of a thermal channel as a result of the interaction of a focused beam of CO₂-laser radiation with a soot aerosol is experimentally investigated. The dynamics of the refractive index and the temperature of the thermal channel were recorded with the help of an interferometer. The dependence of the medium temperature on distance along the beam axis were obtained. The development time of free convection and the setting-up time of the steady state of the process were determined. Numerical values of the refractive index and of the temperature at all the points of the region occupied by the thermal channel were calculated from the interferograms using the Abel integral equation.

The interaction of a powerful laser radiation with aerosol particles is accompanied by the formation of temperature and gas halos around the particles, which exert a noticeable influence upon the character of propagation of the radiation.^{1,2} The optical inhomogeneity in the beam channel induced by the laser radiation itself distorts the shape of the beam, while in the case of propagation of a continuous beam the beam is displaced towards the convective flux.³

In the consideration of a number of questions concerning the propagation of powerful laser radiation in refractive channels, a knowledge of the different characteristics of the channels, in particular, the refractive index n , is required. The influence of the refractive index on the phase fluctuations of the sounding beam was investigated in Ref. 4. Results of experimental and theoretical investigations on the propagation of a CO₂-laser beam through a soot aerosol, which took into account the induced refractive index field were presented in Refs. 3 and 5.

This paper presents the results of an experimental determination of the dynamics of the refractive index and of the temperature of the thermal track produced by the interaction of focused CO₂-laser radiation propagating horizontally through a soot aerosol.

The measurement was carried out interferometrically, which provided for the direct measurement of the refractive index field. A shearing interferometer,⁶ which is simple to assemble and tune and makes it possible to observe the varying interference pattern continuously, was used in the experiments. A diagram of the experimental setup is shown in Fig. 1. Radiation from an LG-25B CO₂ laser 2 with wavelength $\lambda = 10.6 \mu\text{m}$ was focused by a salt lens 14 into the center of the aerosol cell 8. The triggering time of the electromagnetic gate 13 was 0.6 ms. The dimensions and the path of the focused beam of CO₂-laser radiation in the aerosol cell are represented in Fig. 2 by the dashed line. The power P of

the acting radiation was measured using an IMO-2 powermeter 16 located behind the disk attenuator 15. The value of P in our experiments was equal to 18 W, which gave the value of the radiation intensity I at the point of the beam constriction $3.1 \cdot 10^7 \text{ W/m}^2$.

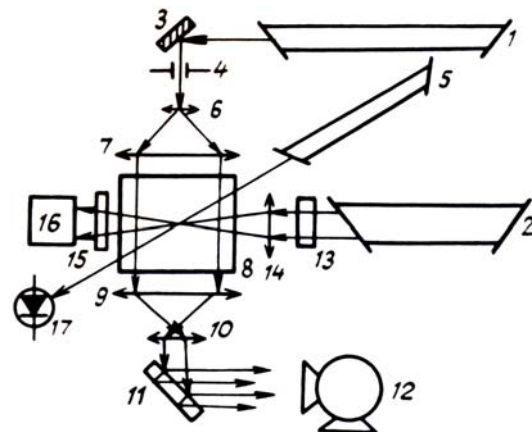


FIG. 1. Diagram of the experimental setup.

PM-100 soot was used as the aerosol. The aerosol concentration was $\sim 10^5 \text{ cm}^{-3}$ in the cell (length $l = 5 \text{ cm}$) and the mean diameter of the particles was $\sim 9 \mu\text{m}$. The absorption coefficient of the aerosol in the cell was estimated using the Bouguer-Lambert-Beer law by measuring the attenuation of radiation from a He-Ne laser 5, and was found to be $\sim 0.03 \text{ cm}^{-1}$.

The sounding radiation of an LG-38 He-Ne laser 1 was diluted by a microobjective 6 and then collimated by a long-focal-length lens 7 up to 8 cm in diameter in order to completely cover the investigated region in the aerosol cell. From there it was directed onto the objective of the SKS-1M motion picture camera 12 by means of the objectives 9 and 10 and a tapered glass plate 11.

The interference patterns of the appearance and development of the thermal field were thus successively recorded on film. The interference pattern consisted of interferograms with bands of finite width.⁷ The frequency of the carrier bands in our experiments was 5 cm^{-1} .

The interference cinegrams of the process which we obtained indicate that the thermal field has an axial symmetry during the initial period of the interaction. This makes it possible to obtain a quantitative measurement of the refractive index distribution. Free convection then develops after a time of the order of $\sim 20 \text{ ms}$. After $\sim 540 \text{ ms}$ the process relaxes, and, in spite of the removal of the particles by the convective fluxes and Brownian movement of the particles, the interference pattern does not change.

Numerical values of the refractive index were calculated from an interferogram obtained 10 ms after the beginning of the action of the CO_2 laser, using the Abel integral equation.^{7,8} A chart of the thermal field isolines is shown in Fig. 2, the z axis direction coinciding with the beam direction of the CO_2 laser.

According to Ref. 2, the effective refractive index distribution of the medium n_{eff} , determined using the average heat discharge of the particles per unit volume of the medium, should be taken as the obtained distribution of n . That is, n_{eff} is the average value of the irregularly distributed value of n in the thermal field. The one-to-one correspondence between the value of n and the temperature T (Ref. 8) makes it possible to determine the average temperature distribution T_{eff} , the values of which are given in the table.

TABLE I

No. of isoline	n_{eff}	T_{eff} , K
1	1.000265	293.0
2	1.000250	310.6
3	1.000225	345.0
4	1.000185	419.7
5	1.000145	535.5

A qualitative analysis of the interferograms and the photography of the channel of the focused beam of the CO_2 laser has shown that in the region adjacent to the entrance window of the cell, strong absorption of radiation occurs accompanied by a bright luminescence. The liberation of heat is greater in this region than in the far one, and the medium temperature on the beam axis reaches $\sim 1100 \text{ K}$.

The dependence of the medium temperature on distance along the beam axis 15 ms after the beginning of action is shown in Fig. 3. Comparison of Figs. 2 and 3 indicates that, despite the strong heat liberation at the entrance to the aerosol cloud, the transverse dimension of the field at the exit exceeds the entrance dimension by a factor of 1.5–2. This circumstance is explained by strong defocusing of the CO_2 -laser beam at the initial moment of the process. It can also be seen from Fig. 2 that the

transverse dimension of the thermal field essentially exceeds the diameter of the beam. Therefore, the values of the temperature and the refractive index can be taken to be constant over the cross section perpendicular to the direction of propagation of the radiation.

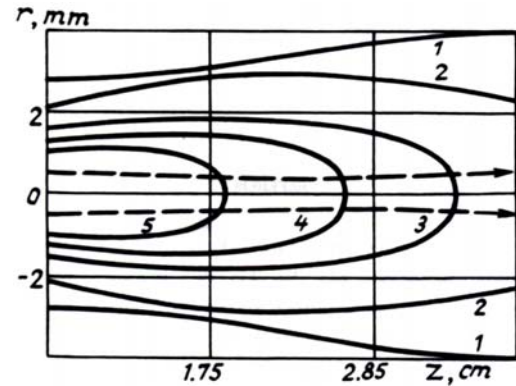


FIG. 2. A chart of the isolines of n_{eff} and T_{eff} . The numerical values of the isolines are given in Table I.

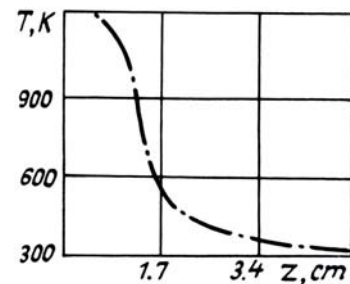


FIG. 3. Dependence of the medium temperature T_{eff} along the axis of a beam of CO_2 -laser radiation on the distance from the entrance window 15 ms after the beginning of the process.

Errors in determining n_{eff} are due mainly to the degree of accuracy or lack of it in the construction of the function of the number of interference bands,⁷ and to deviation of the shape of the object from axial symmetry due to convection. Errors in the numerical integration of the Abel equation by the step approximation method, which we used in this paper, do not exceed 0.5% near the symmetry axis of the phase object according to the results of Ref. 8. The total error was $\sim 5\%$. Therefore, this method can be used successfully to study the dynamics of the thermal field of a powerful laser beam propagating in a combustible aerosol.

It should be noted that in the case of experiments with horizontal beam propagation it is difficult to obtain quantitative dependences after the appearance of convection since the shape of the investigated object becomes highly irregular. But visualization of the thermal field makes it possible to study the appearance and establishment of the convective fluxes produced by thermal blooming of the laser beam.

REFERENCES

1. V.E. Zuev and Yu.D. Kopytin, *Izv. Vyssh. Uchebn. Zaved., Fiz. No. 11, 79 (1977)*.
2. G.M. Strelkov, in: *Abstracts of Reports at the Second All-Union Conference on Propagation of Laser Radiation in a Disperse Medium, Part II, Obninsk, 1982, p. 157*.
3. Yu.N. Grachev and V.S. Loskutov, in: *Abstracts of Reports at the Fifteenth All-Union Conference on the Propagation of Radiowaves, Alma-Ata, 1987, p. 383*.
4. M.S. Belen'kii, I.P. Lukin, V.P. Mironov, et al., in: *Abstracts of Reports at the Eighth All-Union Conference on Laser and Acoustic Sounding of the Atmosphere, Part II, Tomsk, 1984, p. 37*.
5. Yu.N. Grachev, V.S. Loskutov, and G.M. Strelkov, in: *Propagation of Powerful Optical Radiation in a Solid Aerosol (Interinstitutional collection), Barnaul, 1982, p. 19*.
6. G.I. Mishin, ed., *Investigation Methods in a Ballistic Experiment* Nauka, Moscow (1979).
7. Yu.I. Ostrovskii, M.M. Butusov, and G.V. Ostrovskaya, *Holographic Interferometry* Nauka, Moscow (1977).
8. V.S. Abrukov and V.M. Mal'tsev, in: *Investigations of Unstable Combustion Processes (Interinstitutional collection), Cheboksary, 1984, p. 87*.