ON INTERFERENCE MEASUREMENTS IN GAS DYNAMICS

PHYSICS

1970

SovietRxiv

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

UDC 535

PHYSICS

E. P. KAZANDZHAN, V. S. SUKHORUKIKH

ON INTERFERENCE MEASUREMENTS IN GAS DYNAMICS

(Presented by Academician I. V. Obreimov on 10 III 1970)

In interference patterns obtained in gas-dynamic studies ([1]-[3]), there is often a break in the fringes, or a strong crowding of them, or other features that prevent one from following the course of the fringes over the entire pattern (Fig. 1). In such cases, in order to carry out interference measurements, along with the pattern in monochromatic light it is necessary also to use a pattern with achromatic fringes (Fig. 2). The need to obtain two interference patterns complicates the apparatus and the experiment, and sometimes substantially hampers the measurements—for example, when using methods of holographic interferometry. The authors propose a method for carrying out interference measurements using only the pattern in monochromatic light.

Fig. 1. Interference pattern in monochromatic light. (Light source—spark discharge between cadmium electrodes; interference light filter with $\lambda_{\max} = 6438$ Å.)

Let us consider a characteristic and practically important example—interference measurements in the investigation of a supersonic spatial gas flow with a detached shock wave (Fig. 1), separating

the inhomogeneity under study from a homogeneous medium with refractive index n_0.

Let us adopt a rectangular coordinate system xyz (Fig. 3); the x-axis is the direction of the oncoming flow, and the z-axis is the direction of transillumination. The interference pattern is observed in a plane parallel to the plane xy;

Fig. 2. Interference pattern with achromatic fringes. (Light source: spark discharge between cadmium electrodes; no light filter.)

the adjustment is to fringes of finite width, perpendicular to the x-axis. The contour Γ is the image of the shock wave. Consider some section $x = \text{const}$,

Fig. 2. Interference pattern with achromatic fringes. (Light source: spark discharge between cadmium electrodes; no light filter.)

Figure 2: Fig. 2. Interference pattern with achromatic fringes. (Light source: spark discharge between cadmium electrodes; no light filter.)

perpendicular to the x-axis, passing through the middle of a dark interference fringe outside the contour Γ. The point A_2 is the intersection of the middle of this fringe with the contour Γ. Let us choose, inside Γ, a dark interference fringe whose middle intersects the segment $x = \text{const}$ at a point A_1 close to the point A_2. We determine the difference in optical path lengths for rays 1 and 2, the first of which passes through the inhomogeneous medium and the second through the homogeneous one.

This difference is equal to

$$L = \int_b^c [n(z) - n_0]\, dz, \tag{1}$$

where b and c are the coordinates of the points B and C at which ray 1 intersects the contour γ, the boundary of the inhomogeneity in the section $x = \text{const}$. Owing to the special choice of the points A_1 and A_2 (at the middles of dark interference fringes), the quantity L is a multiple of the wavelength of light λ, i.e. $L = k\lambda$, where k is an integer. In the example considered, to determine the desired quantity k, in addition to the interference pattern in monochromatic light, one uses-

we find: the shape of the contour γ (determined from photographs of interference patterns obtained for different directions of illuminating the flow ([3])) and the distribution of the refractive index n on the contour γ (determined with the aid of known gas-dynamic relations and the Lorentz–Lorenz formula ([2])):

$$n(\gamma) = 1 + (n_0 - 1)(\varkappa + 1)[\varkappa - 1 + 2/M^2 \sin^2 \beta(\gamma)]^{-1},$$

where $\varkappa$ is the adiabatic exponent, M is the Mach number of the incident flow, and $\beta(\gamma)$ is the angle of the surface of the shock wave with the direction of the incident flow.

Let us approximate the distribution of the quantity $n(z)$ on the segment BC by some two-parameter function. Taking, for example, the linear function $n(z) = a_1 + a_2 z$, we shall have:

$$\int_b^c (a_1 + a_2 z - n_0)\, dz = k\lambda, \tag{1'}$$

whence

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

$$k = \frac{c-b}{\lambda}\left(a_1 - n_0 + \frac{c+b}{2}a_2\right); \tag{2}$$

the undetermined approximation coefficients a_1 and a_2 are found from the system of equations

$$\begin{aligned} a_1 + a_2 b &= n(b), \\ a_1 + a_2 c &= n(c). \end{aligned} \tag{3}$$

In accordance with the remark made above, the computed value of k is rounded to the nearest integer, and the resulting deviation is "charged" to measurement errors.

Fig. 3

If $n(z)$ is approximated by a function with a number of parameters greater than two, then the values of $n(b)$ and $n(c)$ are insufficient for determining the approximation coefficients; however, a system of equations of type (3) can be closed by introducing some additional assumption, for example, one relating the distributions of the refractive index along ray l and along the arc of the contour γ cut off by this ray ([3]).

In the case of an axisymmetric inhomogeneity (when the contour γ is a circle of radius R), the problem is substantially simplified, since from approximating the function n with respect to z one can pass to approximation with respect to the radial coordinate; moreover, this approximation extends to all rays that have passed through the segment A_1A_2 (Figs. 3, 4), and not only to the ray that has passed through the point A_1. Relation (1) takes the form

$$2\int_{y_i}^{R} [\,n(r) - n_0\,]\, r\,(r^2 - y_i^2)^{-1/2}\, dr = k_i\lambda, \tag{1”}$$

Fig. 4

where y_i is the distance of the centers of the dark interference fringes to the axis of symmetry x; k_i are integers changing by unity when passing to the neighboring fringe.

Having chosen an approximating function for $n(r)$ and integrated $(1'')$, we obtain equations relating k_i and the approximation coefficients. Since, among all the numbers k_i, only one can be regarded as unknown (all the others are expressed in terms of it in an elementary way), the number of these equations must exceed by one the number of approximation coefficients. Finding any one of the numbers k_i solves the problem posed.

Knowledge of the distribution of the refractive index on the boundary γ simplifies the solution of the problem, but is by no means obligatory. In the axisymmetric case, knowing the value $n(R)$ makes it possible to obtain a relation between the approximation coefficients, which makes it possible to reduce by one the number of equations required for closing the system being solved. In the three-dimensional case, lack of knowledge of the distribution $n(\gamma)$ can be compensated by the presence of some preliminary information ([3]) about the nature of the distribution of n in the segment bounded by ray 1 and contour γ (Fig. 3).

Let us note that the validity of the chosen approximations of n can sometimes be checked, for example in the axisymmetric case, by calculating the coordinates of the midpoints of the interference fringes outside the approximation interval and comparing these calculated coordinates with the coordinates of the fringes measured from the interferogram.

An important question is the error in determining the quantity k. It is necessary that the modulus of the error δk be less than 0.5. In accordance with this requirement, the measurement conditions must be chosen. For example, in the axisymmetric case, for the simplest approximation $n(r) = n_1 = \text{const}$, we have

$$\delta k \approx k \frac{\delta(R - y_1)}{R - y_1}.$$

If, say, $k = 5$, and the error in reading linear dimensions from the interferogram (on the full-scale scale) is ± 0.3 mm, then the value $R - y_1$ must exceed the error of its measurement by a factor of 10.

The proposed method has undergone practical verification. For interferograms of axisymmetric and three-dimensional supersonic flows (one of them is presented in Fig. 1), values of k determined by two methods were compared: by the method considered in the present article and by the usual one, i.e., using an interferogram with achromatic fringes (Fig. 2), photographed simultaneously with the pattern in monochromatic light. The results obtained by the two methods agree: the values of k calculated by the proposed method (constant and linear approximations were used in the axisymmetric case, and linear and parabolic approximations in the three-dimensional case) deviate from the integers found from the patterns with achromatic fringes by no more than 0.5 (the required values $k \leq 16$).

The method was used in experimental investigations carried out by holographic methods and with the aid of a polarization shear interferometer.

The authors express their gratitude to I. V. Obreimov for a critical discussion of this work, and also to Yu. A. Mozhaev for friendly assistance in performing some calculations.

Received
5 III 1970

REFERENCES CITED

1. A. N. Zakharyevsky, *Interferometers*, Moscow, 1952.
2. G. V. Lipman, A. Roshko, *Elements of Gas Dynamics*, Moscow, 1960.
3. S. M. Belotserkovsky, V. S. Sukhorykh, B. S. Tatarenchik, *Journal of Applied Mechanics and Technical Physics*, No. 4, 95 (1964).

Note: Figure translations are in progress. See original paper for figures.