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APPLICATION OF AN INTERFEROMETER WITH A DIFFRACTION GRATING TO THE STUDY OF FLOW AROUND MODELS IN A SHOCK TUBE

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In experimental gas dynamics, when studying the flow around models by a high-speed gas stream, it is necessary to carry out a large number of measurements simultaneously. The form and location of shock waves and compression discontinuities, the distributions of density, pressure, temperature, and gas velocity in the stream and near the model, and the parameters determining the state of the model—these are far from a complete list of the quantities that must be measured. In addition, all the measuring equipment is under very difficult conditions: as a rule, the instruments are located in large production rooms with rapidly changing temperature; vibrations play a major role. All these reasons have led recently to the testing of various versions of a measuring complex that make it possible to solve optimally the problem of determining the characteristics of the interaction of a gas stream with a model. From this point of view, it is of interest to investigate the possibility of using, for measurements in gas-dynamic installations, an interferometer with a diffraction grating ([1]). This instrument can easily be obtained from ordinary shadowgraph instruments ([2]) available at aerodynamic installations. Such a combination makes it possible simultaneously and with sufficient accuracy to determine the shape of shock waves (for which the shadowgraph instrument is more convenient) and to carry out quantitative measurements of the density of the gas stream. The formation of both interfering light beams is performed by the same parts of the instrument; therefore it is considerably less sensitive to vibrations than the commonly used interferometers of the Jamin–Mach type.

Up to the present time, an interferometer with a diffraction grating has been used to study stationary, comparatively smoothly varying optical inhomogeneities, mainly to investigate the quality of photographic lenses. The application of the interferometer to the study of nonstationary gas inhomogeneities will make it possible not only to obtain data valuable for gas dynamics, but also to develop a measurement method suitable for solving many other

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problems.

When studying gas-dynamic processes by means of interferometers with a diffraction grating, the investigator is faced with the necessity of solving a number of questions: the choice of the interference scheme and of the amount of defocusing, the determination of the magnitude and location of the interfering fields, the selection of light sources, photographic film, light filters, etc. A multitude of interrelated and at the same time contradictory requirements arises. For example, improving the monochromaticity of the light, which is necessary for increasing the contrast of the fringes, entails a loss of illumination of the interference pattern. An increase in the illumination of the image, achieved by increasing the size of the illuminating slit, leads to a decrease in the contrast of the fringes. Consequently, it is necessary to find the optimum conditions for carrying out the experiment, based on the nature of the inhomogeneity under study, the aims of the investigation, and the available apparatus and materials. Often it is advisable, in order to improve some characteristics, to accept a deterioration of others.

We shall dwell on individual questions that arise when choosing the conditions of the experiment.

Calculation of the contrast of the interference fringes and of the illumination of the image shows that it is most advantageous to use diffraction gratings that produce not only amplitude but also phase changes in the light wave incident on them. However, we had at our disposal only amplitude gratings with periods $p = 0.01;\ 0.02;\ 0.04$ mm and with one and the same ratio of the width of the transparent line ξ to the period p ($\mu = \xi/p = 0.5$). Therefore, in what follows we shall discuss the optimum experimental conditions with gratings of this kind.

Fig. 1. Diagram of the arrangement of the details of the gas flow and of the model in the field of the instrument

In investigations in shock tubes, the dimensions and position of the working field (Fig. 1) must be such that it is possible to see the nozzle section 1, the model 2, the shock waves 4 and 5, and the gas flow behind the shock wave 6. The comparison field is best taken in the rear part of the window, free from the gas flow. Its size and position (and, correspondingly, the direction of the interference fringes) depend on the position of the nozzle, the model, the holder, and the shock wave, as well as on the interferometer scheme. The field size b (and the distance between the interfering fields) is related to the grating period p and to the wavelength of light λ by the relation $bp = f\lambda$, where f is the focal length of the main objective of the receiving part of the shadow instrument.

Fig. 2

Figure 2: Fig. 2

In practice, only three interference schemes can be considered: $+1, -1$; $0, 1$; $0, +1, -1$ orders. With the gratings available, the intensities of the beams of the second and subsequent even orders are zero. The intensities of the third and higher odd orders are small, and it is inexpedient to consider their interference.

The maximum working field can be obtained with the interference scheme of the 0 and 1 orders. It is approximately equal to half the field of the shadow instrument and is achieved when using an IAB-451 and a light filter with $\lambda = 0.5\,\mu$, if $p = 0.01$ mm (100 lines/mm). In the interference scheme of the $+1, -1$ orders, the field can be made equal to 1/3 of the field of the shadow instrument, since in this case the interfering fields are separated.

The dimensions of the inhomogeneity and of the models in our experiments made it possible to limit ourselves to a field of 40–50 mm. It was therefore of interest to carry out a comparative analysis of the interference schemes with respect to other parameters (illumination, contrast of the interference pattern, etc.).

The rapidity of the process under study made it necessary to use a pulsed light source with a flash duration of $\sim 1\,\mu$sec. Therefore, as the diaphragm limiting the image of the light source in the focal plane of the collimating part of the shadow instrument, only diffraction gratings could be used; when single slits were employed, the illumination of the image was insufficient to obtain normal blackening densities of the photographic material.

The available gratings made it possible to implement two two-beam interference schemes. In the first of them, waves of the zero and first orders interfered. The size of the working region could be brought up to half the field of the shadow instrument. The contrast of the interference fringes in monochromatic light was 0.58. In the second scheme, with interference of the zero and first waves, the size of the working region could be brought up to 1/3 of the field of the shadow instrument; the working and comparison fields are separated, the contrast is 0.64, and the zero fringes are achromatic. The illumination of the image at the maxima in the first scheme is 1.75 times greater than in the second.

Analysis of the practical use of each of the arrangements showed that it is more advantageous to use the second arrangement. The separation of the working fields, the achromaticity of the fringes in the zero photograph, and, most importantly, the higher contrast prove to be more significant than the gain in field size and illumination. Therefore, in the experiments, interference of the $+1$ and -1 orders was mainly used. In the illuminating part of the shadow instrument there was a diffraction grating of 100 lines/mm, and in the receiving part one of 50 lines/mm. Interference light filters with $\lambda = 0.514$ and $0.628\,\mu$ were used for monochromatizing the light.

Fig. 3

Figure 3: Fig. 3

Fig. 2

The experimental technique on shock tubes, details of their design, and flow characteristics are described sufficiently well in the literature ([3],[4]). The time delay was adjusted so that the flash of the pulsed light source occurred at the moment when the working gas flow following the shock-wave front reached the model placed in the vacuum chamber, the flow around which was being investigated.

The general appearance of the zero photograph is given in Fig. 2a. It is seen that the field size is quite sufficient for the investigations: it is substantially larger than the size of the model and is comparable with the dimensions of the nozzle and the working rhombus of the flow. Along with the image of the model in the main interference pattern, in which the superposition of the +1-st and −1-st images of the working field and of the comparison field takes place, with the corresponding adjustment one can see the zero image of the model and the interference pattern of the superposition of the −1-st and −3-rd images. The limitation of the working field in height was due to the design of the holder. When a curved holder was used, this limitation was removed.

Fig. 3. Lines of equal gas density near a wedge

Experimental photographs of the flow around a wedge model by a gas stream were taken with various instrument adjustments: for a finite and an inf–

finite fringe width. Typical interferograms for each case are presented in Figs. 2b, c. With fringes of finite width, the lines of equal density of the gaseous nonuniformity near the model were lines of equal displacement of the interference fringes. They were found after the photographs were interpreted, in the course of which the positions of the interference fringes relative to characteristic details of the photograph (the nozzle edge, the model, etc.) were compared on the zero and working photographs. With fringes of infinite width, the interference fringes themselves are the lines of equal density. In this case, even a visual study of the photographs makes it possible to draw certain conclusions about the density distribution in the gas flow and near the model. But this advantage is substantial only in the case where the nonuniformity displaces the wave front sufficiently strongly, so that a large number of fringes is visible in the working photograph. If the number of fringes is small (1, 2), the advantage of clarity is lost. In this case it is necessary to use a photometric method of interpretation. This substantially complicates the interpretation process, but makes it possible to increase the accuracy of determining the density.

In our case it was more convenient to carry out the interpretation from photographs with adjustment for finite fringe width. The zero image of the model

Fig. 4

Figure 4: Fig. 4

present in the photograph proved very useful: it contains a flow pattern corresponding to the luminous-point method. From this pattern it is considerably more convenient than from the main interferogram to determine the shape and position of the shock wave.

Fig. 4

The photographs obtained were interpreted: from them the density distribution of the gas flow near the model was found. The interpretation was simplest for photographs with finite fringe width ([5]). A graph of the density distribution of the gas flow behind the discontinuity near the model is presented in Fig. 3. A strong density gradient is seen at the shock wave and near the model. Behind the base of the model the gas density, as usual, falls sharply. For accurate measurements in this region the sensitivity of the interferometer is insufficient, and only the upper limit of the density values can be estimated. For more detailed measurements in this region it is necessary to adjust the instrument for fringes of infinite width and to use a photometric method of interpretation.

Figure 4 gives the flow pattern near a reversed cone, taken by the three-beam interferometry method. The points corresponding to the reversal of fringes were used as a check in interpreting two-beam patterns. Photometric analysis of these photographs, by which a greater sensitivity can be obtained in comparison with two-beam measurements, was not carried out in the present investigations.

In conclusion it should be noted that the use of an interferometer with a diffraction grating for the quantitative study of gas flows has shown the applicability of this instrument for such purposes, has revealed the principal features of its use, and the positive and negative aspects of its application.

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