OPTICAL QUALITY OF FLOWS BEING FORMED BY AXISYMMETRIC NOZZLE CONFIGURATIONS

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Extensive utilization of fine-scale axisymmetric nozzles for gas-flow formation obliges a detailed study of the gas dynamic configuration of such flows and makes the problem of assuring their high optical quality quite urgent.

Analysis of the flow pattern and the results obtained in [1-3] indicate the regular nature of the inhomogeneities in such a flow and the possibility, in principle, of diminishing the phase distortions of the passing radiation because of mutual compensation and averaging along the optical path. Necessary for this is orientation of the flow in a definite manner relative to the direction of radiation propagation [1, 3].

Results are presented in [1-3] for an optical certification of the gas flows formed by axisymmetric nozzle configurations. These results include an estimate of the integral inhomogeneity of the density $\Delta\rho/\rho$ by some method. A deduction about the optical quality of the flow is made according to the magnitude of the density inhomogeneity on the basis of the proportionality $\Delta\varphi$ (phase distortions) of the inhomogeneity Δn (refractive index, that particularly depends on the gas density also).

The optical quality of flows formed by axisymmetric nozzle configurations was estimated in [2] by the Talbot interferometry method for distortions in the medium under investigation of an initially plane probing wave front (WF). One-dimensional radiation directivity patterns in the far zone were constructed for moderate distortions of the WF profile. These results permitted making the deduction about the possibility of obtaining a sufficiently high directivity for the radiation passing thrugh the flow; however, they must be considered as test estimates that permit a judgment about the optical quality of gas flows, but do not reflect the whole completeness of the real physical pattern of both the flow itself and of the singularities in the WF and the radiation directivity pattern.

The real radiation directivity pattern (i.e., the two-dimensional intensity distribution) as well as its characteristics, such as the relative energy fraction in the central loop W_{-1}^{+1} (as compared with an ideal pattern) and the relative axial intensity (the Strouhal number Sh) yield exhaustive information about the optical quality of a medium.

The discrete representation of information in the Talbot interferometry method permitted the total pattern of WF distortion to be obtained by using comparatively simple processing of the interferograms. Measurement of the WF distortion over the whole aperture of the probing beam enclosing a certain flow domain permitted clarifying, estimating, and taking account of a number of flow singularities formed by an axisymmetric nozzle configuration. The primary influence of the system of shock waves on the gasdynamic parameters at short (up to 10 jet calibers) ranges from the axisymmetric nozzle module and on the growth of the total downstream density level is mentioned in [3].

The strong nonlinear downstream density growth detected in experiments and obtained in computations within the limits of the domain being certified that is enclosed by the prob-

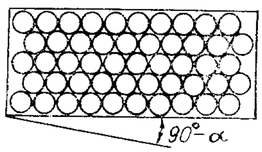

Fig. 1

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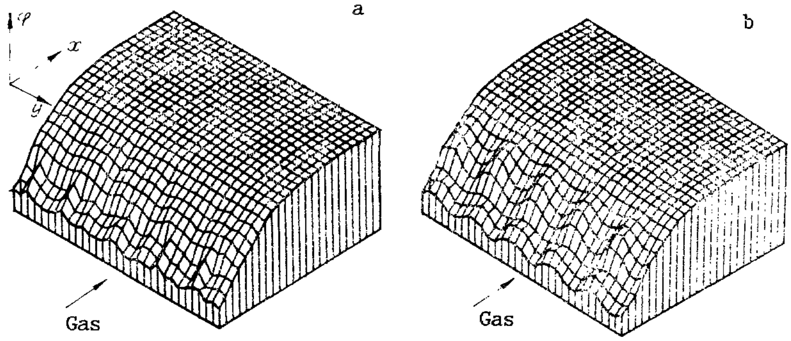

Fig. 2

ing radiation exerts substantial influence on the nature of the WF distortions and, consequently, on the directivity pattern. The WF distortion in the flow direction within the limits of flow domain being certified can significantly exceed the periodic WF distortions in the cross-flow direction whose origin is due to interaction of the fine-scale axisymmetric jets. However, the WF distortion in the direction along the flow is represented sufficiently simply despite the nonlinearity since, first, it occurs only at comparatively short distances (<10 jet calibers) from the module and is, consequently, not decisive for active media in systems with mixing of heterogeneous components; second, even in cases of the need to use the flow section directly after the exit of the axisymmetric nozzle configuration it can easily be taken into account and eliminated physically by comparatively simple means.

Of greatest interest from the viewpoint of influence on the optical flow quality are WF distortions in the transverse flow direction. As mentioned above and in [1, 3], the regular nature of the inhomogeneities in the flow governed by the periodic nozzle arrangement in the configuration assures the possibility, in principle, of diminishing the phase distortions of radiation at the exit from the gas medium.

Results are presented below of a numerical and experimental (by the Talbot interferometry method) investigation of the dependence of the optical quality of flows on their orientation relative to radiation propagation.

Flows are studied that are formed by profiled axisymmetric nozzle configuration with a degree of expansion 36 ($d_* = 1.1$ mm, $d_a = 6.6$ mm). The nozzles are arranged in a checkerboard order (hexagonal stacking) and are inscribed by the exit sections into a 35 × 85 mm rectangle (Fig. 1), the flow is simulated by cold air (α is the angle of orientation of nozzle rows relative to the direction of the probing radiation). The probing WF aperture dimensions are 30 × 30 mm, processing the Talbotgrams was performed on a specially produced automated complex on the base of an instrumental microscope and an electronic computer. The directivity patterns were constructed from the condition of proportional accumulation of the phase distortions during a single passage by radiation over the flow with dimension 1.05 m [2].

Computations of the probing WF distortions and the appropriate directivity patterns were performed under the assumptions of the possibility of separately taking account of the phase shifts acquired by the radiation in a shock-wave system and mixing traces [1, 3]. The characteristic computed WF of radiation that passed a shock-wave system in a flow formed by an axisymmetric nozzle configuration for $\alpha = 19$ and 30° (a and b) are shown in Fig. 2, where x and y are the downstream and cross-flow coordinates, respectively; φ is the phase of the radiation that passed. The phase shift associated with the growth of the general downstream density level substantially exceeds the amplitude of the periodic phase distortions in the other (cross-flow) direction, as is characteristic for zones of primary influence on the shock-wave gas parameters on the flow section near the configuration. It should be noted also that the shock intensity diminishes rapidly and they are practically damped out within the limits of the selected aperture. A WF correction by subtracting the magnitude of the phase shift corresponding to the growth of the general downstream density level was performed in computations of the directivity patterns executed in order to optimize configuration orientation. Analysis of the results of the numerical simulation performed shows that there are preferred directions ($\alpha_1 \approx 6°$, $\alpha_2 \approx 19°$) wherein the radiation formed by the investigated axisymemtric nozzle configuration being propagated along these directions in the flow will acquire minimal phase shifts in the whole aperture. The radiation patterns

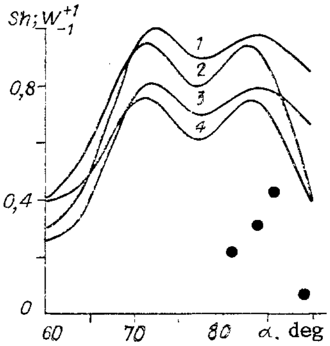

Fig. 3

for these directions are close to ideal: Sh ~ 0.95 as compared with the traditional directions of radiation propagation α = 0 or 90° for which Sh ~ 0.3, i.e., optimal orientation of the nozzle orientation permits a triple magnification of the relative axial intensity in the far zone and the energy fraction in the central lobe of the directivity pattern.

Let us note that a change in α within 0-30° limits for the studied nozzle arrangement diagram exhausts a whole possible set of mutual locations of the configuration and the radiation propagation direction. A change in α within the 30-60° and 60-90° limits is equivalent to a change in the 0-30° band for which the investigation was performed. Displayed in Fig. 3 is the dependence of Sh and W_{-1}^{+1} on the angle of orientation α of the nozzle rows. Curves 1 and 2 are Sh and W_{-1}^{+1} for modeling flows with mixing traces, while 3 and 4 are for modeling flows with a spatial shock configuration and the points are results of experiments.

Analysis of the phase distortions acquired by radiation in a system of mixing traces of jets issuing from axisymmetric nozzles of the configuration under examination shows that, even in this case (for which the influence of shocks is not taken into account), there are optimal angles of orientation that agree with those obtained for the flow section in the zone of shock influence. The significant magnification of the axial intensity and the energy fraction in the central lobe of the directivity pattern is an index of the possibility of a substantial rise in the optical quality when probing at these angles.

The results of experiments confirm the tendencies disclosed by numerical modeling for a change in the optical quality of the medium as a function of the orientation of the axisymmetric nozzle array. Directivity patterns of radiation that passed the flow at different angles (a-d for α = 2, 4, 6, and 8°) are shown in Fig. 4. Comparison of the patterns indicates the presence of an optimal angle whose magnitude α = 4° agrees satisfactorily with one

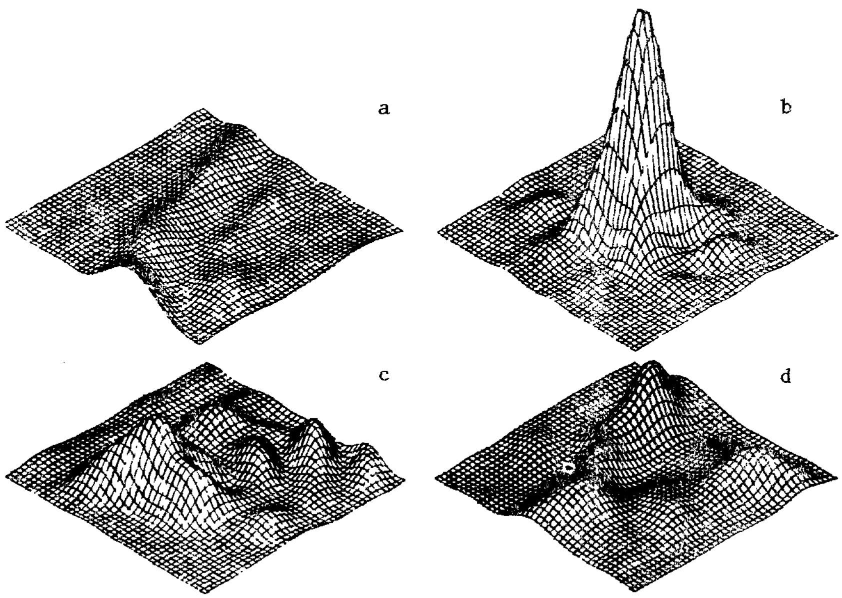

Fig. 4

of the values found in the computations. The experimental results obtained indicate the possibility of a significant improvement in the directivity pattern in the case of optimal array orientation (approximately thrice in comparison with $\alpha = 0$ is the magnification of the relative axial intensity and the energy fraction in the central lobe).

Therefore, the models utilized for the computations are adequate and describe with satisfactory quality the experimentally recorded tendencies of the dependences of the spatial characteristics of the radiation on the orientation of the axisymmetric nozzle arrays, which verifies the good agreement between the computed and experimental values of the optimal angles and the identical relative magnification of Sh and W_{-1}^{+1} for these angles as compared with $\alpha = 0$.

The difference between the absolute computed and experimental magnitudes is explained mostly by the assumption realized in the computed models of the possibility of separately taking account of the influence of the shock and trace system on the gas parameters. Thus, the optical quality of a flow was studied experimentally at a range of 25-55 mm from the array (such a section was enclosed by the aperture of the probing beam), i.e., in the zone of substantial influence of the shock on the gas parameters. In reality there are even developed traces in this flow section; however, their contribution to the accumulation of phase distortions was not taken into account in the computations, which could result in exaggeration of the corresponding computed values of Sh as compared with the experimental while conserving the qualitative nature of the dependence $Sh(\alpha)$. Moreover, a 30-fold magnification of the experimentally measured quantities of the phase distortion during conversion to the geometric path length in the medium ~1.05 m results in a corresponding 30-fold magnification of the influence of the near-wall domains and the flow-initiated shocks that occur in the channel of the experimental installation with a 35 × 85 mm section size. This can also be the reason for the differences in the absolute values of the computed and experimental Sh, where the experimental values found during such a conversion to the large optical path length in the flow will evidently be reduced as opposed to those that could be obtained for real flows in large-scale channels.

The elucidated results of numerical and experimental (Talbot-interferometry method) investigations of the optical quality of a gas flow formed by an axisymmetric nozzle array indicate convincingly the possibility of improving the radiation directivity pattern due to optimal orientation of such flows relative to the direction of radiation emergence.

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