METALLIC SURFACES AND FILMS

PACS numbers: 45.50.-j, 47.27.nf, 47.40.Ki, 47.10.A-

Interaction of Solid Particles from a Gas Stream with the Surface of a Flat Nozzle

A. I. Dolmatov and S. A. Polyviany*

*National Aerospace University 'Kharkiv Aviation Institute',
17 Chkalov Str.,
61070 Kharkiv, Ukraine*
**Motor Sich JSC,
15 Motorostroiteley Ave.,
UA-69068 Zaporizhzhya, Ukraine*

The study of flow of gas with solid particles in a flat nozzle is performed. The parameters of flow of gas with particles of powder in the flow passage of the flat supersonic nozzle are studied, as well the parameters of interaction between the solid particles of the spray deposited material and surface of the target backing plate by means of mathematical modelling of the three-dimensional constant-property flow of the viscous compressed real gas with solid particles. During the mathematical modelling of the process of flow of gas with solid particles by using highly specialized CFX-Pre 16.2 and CFX-Solver Manager 16.2 software packages the fields of parameters in the nozzle's flow passage and near the target backing plate are obtained.

Key words: deposition, two-phase flow, mathematical modelling, supersonic flow, flat nozzle.

Розглянуто течію газу з твердими частинками у пласкому соплі. Проведено дослідження параметрів потоку газу з частинками порошку у проточній частині плаского надзвукового сопла, а також параметрів взаємодії напилюваного матеріалу з поверхнею підкладки-мішені шляхом математичного моделювання тривимірної стаціонарної течії в'язкого стиснутого реального газу з твердими частинками. У ході математичного моделювання процесу течії газу з твердими частинками з використанням програмних пакетів CFX-Pre 16.2 и CFX-Solver Manager 16.2 отримано поля

Corresponding author: Anatolii Ivanovych Dolmatov
E-mail: a.dolmatov@khai.edu

Citation: A. I. Dolmatov and S. A. Polyviany, Interaction of Solid Particles from a Gas Stream with the Surface of a Flat Nozzle, *Metallofiz. Noveishie Tekhnol.*, **43**, No. 3: 319–328 (2021), DOI: [10.15407/mfint.43.03.0319](https://doi.org/10.15407/mfint.43.03.0319).

параметрів у проточній частині сопла та поблизу підкладки-мішені.

Ключові слова: розпилення, двофазний потік, математичне моделювання, надзвуковий потік, плоске сопло.

(Received September 8, 2020; in final version, December 18, 2020)

1. INTRODUCTION

The development of modern technology is characterized by a constant intensification of operation modes units and individual parts. The development of modern technology is characterized by a constant intensification of operation modes units and individual parts [1]. There is a growing need for solid combination, durable, wear-resistant and heat-resistant surface layer (coating) with a plastic, viscous, crack-resistant and non-scarce base in the parts. The implementation of this approach became possible mainly through the use of protective functional coatings, and first of all, gas thermal ones. At this time, gas thermal spraying is considered one of the most promising technologies in terms of technological capabilities and ecology.

The study's objective is to determine the parameters of flow of gas with particles of powder in the flow passage of the flat supersonic nozzle, as well as the parameters of interaction between the solid particles of the spray deposited material and surface of the target backing plate by means of mathematical modelling of the three-dimensional constant-property flow of the viscous compressed real gas with the solid particles [2–5]. In order to solve the stated task, the methods of computational gas dynamics, dispersed media dynamics, stress-strain state theory and solids mechanics are used [6–8]. The applied mathematical model is based on the classical gas dynamics equations and systems of equations, including the equations of continuity, Navier–Stokes, energy, state of real gases in the form of modified Redlich–Kwong equation, kinematic and dynamic equations of motion of solid particles of finite size in heterogeneous turbulent flow, equations of interaction of solid particle with solid non-deformable target under inelastic and partially inelastic impact, equations of thermal conductivity, *etc.* [9–11].

To solve the differential equation system with partial derivatives under known boundary conditions of mixed type, the approved method of computational mathematics is used, specifically, the control volume method, adapted to calculation of the biphasic medium flow. The approximation of differential equations by algebraic equations is based on discretization of the normal working area by structured hexagonal grids of specified topology with additional cell distribution laws near the solid surfaces for proper modelling of the boundary layer. To adapt the geometric model to the mesh schemes, the specialized multi-

functional CAE-package of the high-level ANSYSCFX16.2 was used for flow calculations and processing of the results.

2. EXPERIMENTAL/THEORETICAL DETAILS

2.1. Task Description and Geometry of Flat Nozzle

The boundary conditions in the framework of the formulated task are the gas pressure at the inlet of the flat nozzle's main and powder input channels, non-leakage and non-slippage at all solid surfaces of the computational area, static pressure equal to atmospheric pressure at the outlet of the computational area and at the free boundaries, static air temperature at the nozzle inlet, as well as mass flow rate of the solid particles. The cross-section of the flat nozzle is shown in Fig. 1.

The geometry of the computational area is constant and predefined. The physical and thermodynamic parameters of air and dispersed mixture are determined according to the tested method of calculating the parameters of gas mixture, dispersed structure and mechanics of solids [12, 13].

The criteria for the type of impact interaction between the particles and surface is determined according to the principles of the solids' elasticity and mechanics theory for the entire range of interaction parameters and allows to estimate the probability of adhesion and repulsion during absolutely inelastic and partially inelastic impacts.

The nozzle consists of three separate sections of formation of the supersonic flow (essentially, three separate independent supersonic flat nozzles), from which the supersonic flows come out forming a single flow with the homogenized parameters. The powder is inputted by means of sidewise blowing into the subsonic part of the nozzle immediately before the trapezoidal section.

For proper modelling of the gas flow process in the nozzle and process of spray deposition on the backing plate, the computational area also includes section of free flow around the nozzle edge and backing plate in the form of cylindrical area 90 mm in diameter and 25 mm high, at that, due to possible presence of the developed vortex flows and parameters near the nozzle and backing plate, which are not fully relaxed, the back end face of this element is defined as a penetrable free boundary with undefined direction of flow.

The physical space of the computational area is approximated by a structured hexagonal mesh consisting of 6 separate block substructures (1 for subsonic channel of main flow, 1 for powder input channel, 3 for flat supersonic nozzles, 1 for connected section of flow between nozzle edge and backing plate). To model the boundary layer and provide the required level of parameter y^+ near the solid surfaces, the law of distribution of the mesh nodes by height along the Hyperbolic edges was specified.

Fig. 1. The cross-section of the flat nozzle.

Fig. 2. Finite-difference mesh (flat nozzle): 1—subsonic channel of main flow; 2—powder input channel; 3—supersonic nozzles; 4—connected section of flow between nozzle edge and backing plate. Side profile (*a*); general view (*b*).

The height of the first mesh is 1 μm and the distribution increment is 1.1, resulting in at least 15 layers of mesh for the boundary layer providing a proper structured mesh for calculating the supersonic flows.

The resulting finite-difference mesh is shown in Fig. 2.

The finite-difference mesh shown in Fig. 2 contains 3964798 elements with a minimum integral performance index of 0.35, which meets the requirements for the structured mesh quality in calculation of the three-dimensional flows and is consistent with previous findings in the literature [12, 13].

3. RESULTS AND DISCUSSION

3.1. Mathematical Modelling of Gas Flow with Solid Particles

During the mathematical modelling of the process of flow of gas with solid particles using highly specialized software packages CFX-Pre 16.2 and CFX-Solver Manager 16.2 the fields of parameters in the nozzle's flow passage and near the target backing plate are obtained. The spherical aluminium 7050 particles of 25 μm in diameter were used. Particles were introduced into the gas flow through the particle input channel as shown in Fig. 1 and at an initial temperature of 20°C and an velocity of 20 m/s. In Figure 3 the distribution of velocity at the powder injection pressure and air supply of 10 atm is shown.

Fig. 3. Flow velocity.

In Figure 3 the sections of the supersonic acceleration of flow in some flat nozzles up to 1.448 m/s (two right sections) and 1.127 m/s (left section) are clearly visible. Changes of the velocity components in the nozzle's flow passage and in the free flow area are shown in Fig. 4.

Fig. 4. Components of velocity during spray deposition of powder: C_x (a), C_v (b).

Outflow from the nozzle demonstrates a pronounced deviation toward the air movement in the subsonic section of the flat nozzle, which is explained by presence of the subsonic areas with stagnant flow in each small flat nozzle (Fig. 3). On the flat surfaces of the nozzle's structural elements there are areas with partial reversed flow created by turbulent vortices in the supersonic sections of the flow (Fig. 4, *b*). The parameters field of the static pressure is shown in Fig. 4.

Figure 5 shows clearly visible points of transition from sonic to supersonic flow in the throats of all three sections of the nozzle accompa-

Fig. 5. Axial pressure distribution.

Fig. 6. Horizontal field of velocity, 1 mm from target backing plate.

nied by pressure drop to 5.78 atm with subsequent decrease to almost atmospheric pressure at the outlet of two right sections of flow and to 1.6 atm in the obstructed left channel (Fig. 4).

The main impact area with pressure of 6.01 atm is observed under the extreme right supersonic channel and corresponds to almost 100% adhesion of the attacking powder particles to the backing plate. In the area of the reverse repulsed flow (Fig. 4, *a*, red section) the maximum

Fig. 7. Horizontal field of velocity, 10 mm from target backing plate.

Fig. 8. Horizontal field of velocity in supersonic nozzles (three characteristic cross sections, isometry).

Fig. 9. Lines of flow.

repulsion of the spray deposited particles with their minimum concentration is observed—up to 25% of partially inelastic impacts with powder content of less than 18% of average value.

In Figures 6–8, the parameter distributions at the characteristic horizontal cross sections of the nozzle and near the backing plate are shown.

In Figure 9 the typical lines of flow for the main and carrying compressed air flows are shown.

4. CONCLUSION

According to the model data, the proposed design of the nozzle results in almost uniform distribution of particles on the surface of the main impact area in the nozzle's shadow on the target backing plate and proper homogenization of the dispersed flow structure in two supersonic nozzles nearest to the powder input channel. The fields of velocity obtained in the supersonic sections, however, indicate strong irregularity of flow in the flat nozzle and necessity for additional profiling of the structural elements responsible for the supersonic nozzles formation.

REFERENCES

1. A. I. Dolmatov, S. V. Sergeev, M. O. Kurin, V. V. Voronko, and T. V. Loza, *Metallofiz. Noveishie Tekhnol.* **37**, No. 7: 871 (2015).
2. L. I. Sedov, *Mekhanika Sploshnoy Sredy* [Continuum Mechanics] (Moscow: Nauka: 1970) (in Russian).

3. G. N. Abramovich, *Prikladnaya Gazovaya Dinamika* [Applied Gas Dynamics] (Moscow: Nauka: 1968) (in Russian).
4. F. M. White, *Fluid Mechanics* (New York: McGraw Hill: 2011).
5. H. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method* (Harlow: Prentice Hall: 2007).
6. H. Lomax, Thomas H. Pulliam, and David W. Zingg, *Fundamentals of Computational Fluid Dynamics* (NASA Ames Research Center: 1999).
7. G. Shlikhting, *Teoriya Pogranichnogo Sloya* [The Boundary Layer Theory] (Moscow: Nauka: 1974) (in Russian).
8. F. S. Sherman, *Viscous Flow* (McGraw-Hill College: 1990).
9. D. C. Wilcox, *Turbulence Modeling for CFD* (DCW Industries: 2006).
10. J. D. Anderson, *Modern Compressible Flow* (Tata McGrawhill India Pvt Ltd: 2012).
11. P. Davidson, *Turbulence: An Introduction for Scientists and Engineers* (Oxford University Press: 2015).
12. B. Samareh, O. Stier, V. Lu, and A. Dolatabadi, *Journal of Thermal Spray Technol.* **18**, Nos. 5–6: 934 (2009).
13. Tien-Chien Jen, Longjian Li, Wenzhi Cui, Qinghua Chen, and Xinming Zhang, *International Journal of Heat and Mass Transfer*, **48**: 4384 (2005).