REVIEW

of the dissertation work by Tan Kun

on the topic «Development of supersonic nozzles for cold spraying»

presented for the degree of Doctor of Philosophy

in the field of Knowledge 13 Mechanical Engineering

in the specialty 134 Aerospace Engineering

Relevance of the Dissertation Topic.

Cold gas dynamic spraying is an emerging coating preparation process technology developed in recent years. It is widely used in the field of aerospace technology. The cold gas dynamic spraying system is mainly divided into two important parts: the powder particles are accelerated by the high-speed gas flow in the nozzle and the powder particles are deposited on the substrate to form a coating.

The critical speed obtained after the powder particles are accelerated in the supersonic nozzle is an important prerequisite for determining whether the powder particles can be deposited on the substrate. There are many factors affecting the powder particles during the acceleration process, so it is necessary to systematically study the acceleration characteristics of the powder particles in the nozzle. Multi-parameter coupling analysis can more accurately characterize the acceleration of the powder particles in the nozzle. The cold spray nozzle is an important part of this technology. It is particularly important to explore the new structure of the cold spray nozzle based on the traditional linear nozzle, especially to achieve the spraying of some special and complex external parts and the inner surface of the parts.

The time for the powder particles to be deposited on the substrate surface is extremely short. During the deposition process, the deformation process of the powder particles cannot be accurately observed, and it is difficult to understand the principle and process of coating formation. Through numerical simulation, the deformation of the powder particles during the deposition process was observed. Comprehensive analysis and research on the methods used to simulate cold spray particle deposition is very noteworthy. Through the comparative analysis method of numerical algorithms,

the model used to simulate particle deposition is determined according to the conditions and goals required for powder particle deposition. During the cold spray process, powder particles are randomly distributed in a specific space. Therefore, the traditional regularly arranged powder particles cannot accurately represent the state of real cold spray powder particles. Therefore, the multi-particle model with disordered distribution in a specific space is worth studying. Using numerical simulation methods to predict and optimize coating porosity has better economic value.

Evaluation of the Scientific Validity, Credibility, and Novelty of the Dissertation's Research Findings.

The results of the dissertation obtained by the author were carried out at the Department of Aircraft Engine Production Technology of the National Aerospace University named after M. E. Zhukovsky «Kharkiv Aviation Institute» in the implementation of the state budget research project of the Ministry of Education and Science of Ukraine: «Development of aggregate technology of restoration and repair of aviation (helicopters) parts by cold spraying with post process machining of deposited coatings» (№ ДР 0122U001341) during 2020-2022.

In the presented work, the author used modern theoretical and numerous modeling methods. The theoretical part of this dissertation uses computational fluid dynamics, gas dynamics, and finite element numerical analysis of solid-liquid two-phase flows consisting of micron particles and gases. Multi-parameter coupling optimization of the velocity of powder particles uses: response surface analysis method and GA+BPNN method. Among them, the SPH, the ALE, and the CEL methods were used to simulate the deposition of single particles/multiple particles on the substrate through numerical simulation. The establishment of the Al6061 multi-particle model was implemented using Solidworks, CaitaV5 and Python programming codes respectively; the response surface analysis method was used to optimize the coating porosity.

The scientific novelty of the dissertation's research is as follows:

1)	for the first time, a method of profiling supersonic single- and multi-channel right-angle nozzles for cold gas-dynamic spraying of coatings on internal and out-off-view surfaces was proposed, which provides the necessary values of the speed of powder particles at the exit of the nozzle for their adhesion to the substrate when the flow is turned by 90°.

2)	For the first time, based on the results of numerical modeling, the dependence of the temperature-velocity characteristics of the powder particles at the exit from the right-angle nozzle on the material of the particles, their size, temperature and gas pressure at the entrance to the nozzle was obtained.

3)	For the first time, an approach to assigning cold gas-dynamic spraying modes is proposed, based on the planning of a multi-factor experiment, response surface methodology and GA+BPNN, which allows assigning the technological parameters of coating sputtering, which ensure that the powder particles achieve the speed necessary for their adhesion to the substrate.

4)	For the first time, on the basis of numerical modeling and the planning methodology of a multifactorial experiment, the dependences of porosity on particle speed, its temperature, and the temperature of the substrate in the studied ranges of values were obtained.

Thus, the scientific tasks proposed in the dissertation – the study of velocity characteristics of particles in a cold spray nozzle, development of a cold spray nozzle and single/multi-particle deposition - have been fully accomplished, and the applicant has fully mastered the methodology of the scientific activity.

Assessment of the Dissertation Content, Its Completeness, and Adherence to the Principles of Academic Integrity.

The dissertation of applicant Tan Kun fully complies with the Standard of Higher Education in specialty 134 Aerospace Engineering and corresponds to the areas of scientific research in accordance with the relevant educational program. The presented dissertation work was completed at a high scientific level and is a fully completed scientific work.

Based on the report on the originality of the dissertation, it can be concluded that Tan Kun's dissertation is the result of independent research and does not contain elements of falsification, compilation, fabrication, plagiarism or borrowing. The ideas, results and texts of other authors presented in the dissertation work have appropriate links to sources.

The text of the dissertation manuscript does not contain signs of violation of the principles of academic integrity.

Language and Style of Presenting the Results.

The dissertation has been written in English and presented consistently, in a scientific style, using generally accepted terminology. The dissertation material, description and mathematical calculations are laid out consistently, logically and in an accessible form. For all abbreviations that are not generally accepted or little-known, transcriptions are provided at the first mention in the text.

The structure and scope of the dissertation. The dissertation consists of an abstract, introduction, 4 chapters, conclusions and an appendix.

The **Introduction** provides the rationale for choosing the research topic and its significance, as well as the object, subject, purpose and objectives of the research, as well as the relationship of the work with scientific topics, scientific novelty and practical results of the research and its validation.

The **chapter 1** gives an overview of the research problems and the status of publications, mainly focusing on solving the problems in the dissertation work, especially the study of the gas dynamics of two-phase flow in the supersonic nozzle of cold aerodynamic spraying by numerical modeling methods, and the study of the interaction of powder particles with the substrate during high-speed deposition and coating formation.

The **chapter 2** presents the main equations describing the aerodynamic characteristics of the flow in the supersonic nozzle of cold gas dynamic spraying, and also introduces the phenomena occurring when powder particles interact with the surface during the spraying process.

The **chapter 3** studies the influence of the cold spray nozzle on the acceleration of particles, parametric optimization of spraying parameters, and presents the results of the development of rotating single-channel and multi-channel nozzles for high-pressure cold pneumatic spraying for coating the inner surface of parts.

The **chapter 4** presents the results of numerical simulations of the high-speed interaction of powder particles of homogeneous and heterogeneous materials with the substrate at the moment of deposition during cold pneumatic spraying.

Conclusion briefly describes the main results of the research of the dissertation and proposes promising tasks for possible further research.

Appendix is a multi-particle model established using Python programming code.

The dissertation adheres to the requirements outlined in the order of the Ministry of Education and Science of Ukraine dated January 12, 2017, No. 40, "On Approval of the Requirements for the Dissertation Formatting".

Publication of Dissertation Results.

The results of the dissertation work were published in 20 articles. Among them 5 articles in scientific periodical publications included in category «А» of the List of scientific specialized publications of Ukraine, or in foreign publications indexed in the Web of Science Core Collection and/or Scopus database; 8 articles in scientific periodical publications included in the List of scientific specialized publications of Ukraine (category «Б»); and 7 conference proceedings (5 of them indexed in the Scopus database: Integrated computer technologies in mechanical engineering (ICTM). ICTM 2021 and ICTM 2023; International Conference on Mechanical Engineering and Materials (ICMEM2020); International Conference on Artificial Intelligence and Advanced Manufacturing (AIAM2021 and AIAM2023)).

Thus, the scientific results described in the dissertation are fully explained in the scientific publications of the acquirer.

Disadvantages and comments to the dissertation work.

Among the disadvantages and comments, the following should be noted:

1.   Since the dissertation is related to the development of supersonic nozzles for spraying, particularly rotary nozzles, it would be worth reviewing the literature to provide existing analogues of such nozzles.

2.   The dissertation does not describe how the geometric dimensions of the channels of multi-channel nozzles were calculated.

3.   Paragraph 3.2 shows the results of studies of the influence of temperature and gas pressure, as well as the size of powder particles on the speed of Cu particles in the form of graphs, but no explanation is provided as to how exactly these factors affect the optimization parameter.

4.   In Chapter 4, numerical modelling of the deposition of powder particles with the substrate and prediction of the porosity of the coatings is performed, but the obtained results are not compared with experimental results, in particular, obtained by other authors.

5.   The dissertation contains stylistic and spelling errors.

I believe that the comments expressed are not decisive, don't reduce the general scientific novelty and practical significance of the results and don't affect the positive evaluation of the dissertation work, but are aimed at further research in this area.

Conclusion on the dissertation work.

The dissertation work of the applicant for the scientific degree of Doctor of Philosophy Tan Kun on the topic "Development of supersonic nozzles for cold spraying" is a fully completed work at a high scientific level. The applicant adhered to the principles of academic integrity. The presented dissertation work is a comprehensive scientific study that solves a research problem that is important for the field of Knowledge 13 Mechanical Engineering. The dissertation work is relevance, practical value, and scientific novelty, fully meeting the requirements of the current legislation of Ukraine as outlined in paragraphs 6-9 of the "Procedure for awarding the degree of Doctor of Philosophy and revoking the decision of a one-time specialized

academic council of a higher education institution, research institution, on awarding the degree of Doctor of Philosophy," approved by the Resolution of the Cabinet of Ministers of Ukraine on January 12, 2022, No. 44.

The applicant Tan Kun deserves to be awarded the degree of Doctor of Philosophy in the field of Knowledge 13 Mechanical Engineering, in the specialty 134 Aerospace Engineering.

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