REVIEW

on a dissertation work

for the acquisition of the educational and scientific degree **"Doctor"**

Author of the Dissertation: **M.Sc Eng. Martin Lachezarov Ralchev;**

Title of the Dissertation: **Emission and Sensor Registration of Microparticles in Inhomogeneous Structures under Uniaxial Deformations;**

Field of Study: *5.2 "Electrical Engineering, Electronics, and Automation"*

Scientific Specialty: *"Elements and Devices of Automation and Computing"*

Reviewer: *Prof. Dr. Eng. August Yordanov Ivanov, Institute of Robotics at BAS.*

1. General Information

Eng. Martin Ralchev was born in 1995 and completed his bachelor's and master's degrees in Electrical Engineering at the Faculty of Electrical Engineering, TU-Sofia, in 2020. He works as an assistant at the Institute of Robotics at BAS. He was enrolled as a part-time doctoral student by order No. 63/18.08.2020 of the Director of IR - BAS. He has fulfilled his individual doctoral study plan. All exams of the doctoral minimum have been successfully passed. The total credit score for the conducted training is very high, totaling 308 credits, significantly exceeding the required minimum of 200 credits. With a decision, Protocol No. 58a/29.04.2024, of an extended seminar of the "SMTRM" section at IR-BAS, it was proposed to the SA of IR to open a procedure for directing towards defense, accepting and dismissing with the right of defense the part-time doctoral student Martin Lachezarov Ralchev. With a decision of the SA of IR, Protocol No. 4/08.05.2024, item 2, the procedure was opened, and the Scientific Jury was selected. The entire procedure was conducted in accordance with the requirements of the Law on the Development of the Academic Staff of the Republic of Bulgaria, the Rules for its application, and the Rules of IR - BAS.

The reviewed dissertation consists of 114 pages of text, 68 figures, and three tables. Structure: Introduction, Five Chapters, Scientific-Applied Contributions, References, List of Publications on the Dissertation, and Declaration of Innovation. The author, together with his scientific supervisor, claims five scientific-applied contributions.

Presented are: Abstract of the Dissertation in the volume of 35 pages, copies of publications related to it, and other documents according to the requirements.

2. Relevance of the Problem Addressed in the Dissertation in Scientific and Scientific-Applied Terms

Improving existing and creating new sensor methods, technologies, including robotic systems for diagnosis and control of the condition of rock formations and concrete composites are of strategic importance. To establish the deformation status and reveal the mechanisms for the occurrence of pre-critical states, the author has highlighted the existence of a large number of measurement sensor elements, components, devices, and recording equipment. The existence of current problems unresolved sufficiently by theory and practice is recognized:

- A drawback is the need to use diverse methods and devices for the various stages of the pre-failure process.
- There is also an absence of a consistent theory of inhomogeneous structures, unlike regular (crystalline) ones.

In the dissertation research, the processes of formation of micro- and nanoparticles under the application of uniaxial stresses on different types of inhomogeneous materials have been analyzed. Reproducible key mechanisms that can contribute to the prevention of structural failures have been identified. The present study contains original methods for controlling and monitoring particle formation. This gives me reason to consider it relevant, important as a scientific-applied study, and especially suitable for technological transfer.

3. Degree of Understanding the State of the Problem and Creative Interpretation of the Literary Material

In the presented dissertation, the doctoral candidate has utilized 71 literary sources to assess the state of the problem, with 42 sources in Latin script and 29 in Cyrillic. The sources range from 1972 to 2023, which I find logical.

Significant progress has been noted in developing numerous approaches and systems related to studying the stress-strain state (SSS) of rock masses. It is recognized that challenges remain relevant due to the complexity and diversity of geomechanical and physicochemical processes occurring in inhomogeneous structures - rocks and concrete.

The research in this dissertation was conducted at the Institute of Robotics at BAS and the National Competence Center "Quantum Communication, Intelligent Security Systems, and Risk Management" - QUASAR at IR.

My overall impression is that the doctoral candidate demonstrates good awareness in the field. He distinguishes between achievements and unresolved problems, which has served him well in precisely formulating the aim and tasks of the dissertation.

4. Correspondence of the Chosen Research Methodology with the Set Goal and Tasks of the Dissertation with the Achieved Contributions

The topic of the dissertation work, the goal, and the tasks set by the author are to investigate the observed effect of particle emission from the surface of inhomogeneous rock systems. Based on this phenomenon, an innovative integrated method for assessing the stress state of these heterogeneous structures is proposed. I particularly appreciate that the development has revealed patterns and properties concerning the emissions of finely dispersed mineral particles under uniaxial compression of rock systems.

The doctoral candidate has provided both theoretical and practical justification for the necessity of the tools, which is crucial for conducting high-quality experimental research.

He has designed and constructed an experimental setup.

Tests and improvements to the experimental apparatus have been carried out, leading to its adaptation for specific research, thus increasing the accuracy of measurements.

Series of rock samples for experimental research have been selected and prepared, taking into account their mineral composition and physico-mechanical properties.

Numerous experimental studies have been conducted, documenting the deformation processes and mineral particle emissions under various conditions and load regimes.

Data processing and analysis have been performed, leading to the identification of key patterns and processes.

For measuring and evaluating their qualities, a test setup for investigating the electrical, magnetosensitive, and thermal characteristics of the fabricated sensors has been designed and manufactured.

My overall impression is that the dissertation is built on the best engineering principle: designing, manufacturing, and experimental research to confirm the main conclusions contributing to the scientific-applied contributions in this work. This approach corresponds to the formulated aim and tasks of the dissertation and aligns well with the claims for contributions.

5. Brief Analytical Characterization of the Dissertation:

The dissertation is structured into an introduction, five chapters, scientific and practical contributions, and a list of references. It meets the requirements of the Law and Regulations on the Development of Academic Staff in the Republic of Bulgaria for a dissertation for the educational and scientific degree "Doctor."

Chapter One: *"State of the Problem"*

This chapter analyzes the current state of research on the stress-strain state (SSS) of rock masses and the existing methods for their study. The development of the problem from antiquity to the present day is traced. Various methods for studying the internal stress and condition of rock masses are reviewed.

The author reviews emission methods for registering the deformation state of rocks. Mechanical testing is used for this purpose, with one of the most commonly used methods being the testing of samples to determine uniaxial compressive strength.

During the deformation and fracturing of rocks, the formation of macro-, micro-, and nanoparticles is observed, accompanied by the emission of acoustic, electromagnetic, and thermal signals, and in some cases, radioactive radiation and radon gas.

The complex use of the presented approaches requires numerous tools and technologies that equivalently realize them. Their mutual coordination is generally practically impossible and could lead to subjective errors.

The new effect of particle generation during uniaxial deformations in inhomogeneous solid structures is an integral method for tracking negative processes from their inception to the onset of pre-failure and failure states. By formulating the comprehensive goal of this study, the tasks for its realization are set.

Chapter Two: *"Formation of Micro-Particles under Load in Rock Structures"*

This chapter analyzes the types of structures in rock formations and their response to physical loads. Factors influencing the increased formation of particles localized in high-stress zones, initiating failure, are determined.

The deformation and fracturing processes in cylindrical cavities are modeled, with the formation of particles from their surface studied. The stress distribution around the cylindrical formations and the dynamics of fraction separation are identified. It is proven that cylindrical cavities simultaneously serve as macro-defects in the rock structure and as amplifiers of deformation effects, influencing the generation process.

An innovative model of deformation and fracturing processes in rock cylindrical cavities under uniaxial load is developed based on the finite element method and the Ansys Maxwell program. Two sources of micro-particle generation in cylindrical cavities are identified: the area of maximum compressive deformations and the zone of maximum tensile stresses.

Chapter Three: *"Experimental Setup for Investigating Dynamic Processes in Inhomogeneous Structures"*

This chapter formulates and justifies a methodology for studying the properties and characteristics of rock samples with different geometric shapes through the effect of particle emission in inhomogeneous structures under uniaxial deformations.

An experimental setup with a corresponding specialized measurement system and sensor module for investigating the dynamic characteristics of rock samples through particle generation under uniaxial deformation is designed, constructed, implemented, and tested.

Chapter Four: *"Experimental Results"*

This chapter describes the samples used in the experiments and outlines the step-by-step research methodology. The information from the results is systematically presented. Data analysis reveals patterns in the behavior of the studied materials under compression. The graphical illustration of the results highlights the high accuracy and reliability of the apparatus and measurement methodologies used. This allows for the adequate reproduction of deformation processes, even with significant differences in initial conditions.

In studying concrete samples subjected to cyclic loading, the structures show signs of weakening in strength characteristics. A sharp increase in particle emission intensity serves as an indicator of impending macro-failure.

The doctoral candidate emphasizes that the exponential increase in particle numbers serves as a reliable indicator for predicting critical states in rocks and concrete. This forms the basis for developing innovative methods and systems for monitoring and assessing the stability of structures composed of these materials.

Chapter Five: *"On the Origin of the Emission Effect and Perspectives for Its Development"*

In this chapter, the author focuses on the physico-chemical interpretation of the effect's origin and his vision for future development. The reproducibility of the new pattern in the same rock structures validates its practical application.

The author proposes an interpretation of micro-fraction emission in rock structures under uniaxial deformations, using elements of the quantum behavior of emitted particles in inhomogeneous systems. An integral sensor method and system for registering the deformation state of rock masses are formulated and developed. A vertical borehole and sensor device for controlling pre-failure states of rock masses are proposed.

6. Scientific and/or Applied Contributions of the Dissertation:

The contributions of the dissertation are of a scientific and applied nature, focusing on proving existing scientific problems with new means and obtaining confirmatory facts. As noted, there are original engineering solutions protected by one patent and two patent applications. The doctoral candidate and the scientific advisor claim five scientific and applied contributions:

1. An experimentally observed previously unknown pattern in solid inhomogeneous systems—rocks and concrete—manifesting in particle generation under high uniaxial deformations. It is proven that the quantities of emitted mineral microfractions in the range of 0.3 μm to 5.0 μm are reproducible for specific rock types in various mountain ranges in Bulgaria.
2. Based on an original methodology, an experimental setup was designed, constructed, implemented, and tested in four variants depending on the geometric shape of the rock samples to study the emission of fine mineral fractions under uniaxial compression. It is equipped with modern sensor devices that measure the characteristics of the emitted microparticles with high accuracy and sensitivity.
3. The functional dependence of particle generation on external factors is determined, with intensity and size varying depending on the type of rocks sourced from different regions of the country. A phenomenological and physico-chemical interpretation of the new pattern is proposed.
4. At deformation pressure levels of rock structures up to the threshold of disintegration, there is a sharp, approximately exponential increase in particles across all size ranges. The quantity of particles is directly proportional to the generating surface of the samples, and the intensity of the

emission process is substantiated to serve as an indicator for predicting their failure.

5. An integral method and system for dynamically determining the stress-strain state of rock masses is proposed and developed. Continuous monitoring of microparticles serves as early warning of pre-failure and emergency situations in critical infrastructure, with applicability in: seismically active areas for detecting tectonic plate folding; mining industry; construction of high-rise buildings and their pre-failure states; prevention of landslides; monitoring the condition of dams, bridges, viaducts, etc.

I accept the substantive aspect of the above-listed scientific and applied contributions. I believe they are sufficient in number and content for the educational and scientific degree "Doctor."

7. Evaluation of Publications Related to the Dissertation:

Three publications, one patent, and two patent applications are presented based on the dissertation. Two publications are single-authored and two are in English:

- S. V. Lozanova, M. L. Ralchev, Sensor system for determining the deformation state of rock masses. Proc. Intern. Scient. Confer. UNITECH 2022, TU - Gabrovo, 2022, ISSN: 1313-230X, vol. I, pp.165-170.
- M. L. Ralchev, Innovative sensor technology for critical infrastructure security purposes, Proc. of I National Scient. Confer. with Intern. Participation „Security and Defence“ 2023, pp. 729-740, 2023.

The publications in Bulgarian include one patent, two patent applications, and:

- S.V. Lozanova, M.L. Ralchev, Particle emission during deformation of rock materials, XIX National Scientific-Practical Conference 2022, Proceedings of the Federation of Scientific and Technical Unions, pp. 139-147, 2022.
- S.V. Lozanova, M.L. Ralchev, Ch.S. Rumenin, Device for determining the physico-mechanical state of deformed rocks and construction materials, Patent No. BG 67599 B1/13.02.2024.
- S.V. Lozanova, M.L. Ralchev, Ch.S. Rumenin, Sensor system for predicting catastrophic macro-failures of buildings and construction structures, Patent Application No. 113607 A1/27.10.2022.
- S.V. Lozanova, M.L. Ralchev, Ch.S. Rumenin, Sensor method for determining the pre-failure state of rock structures, Patent Application No. 113614 A1/09.11.2022.

I find that the publications are sufficient in number and reflect the essential part of the results obtained in the dissertation. I have no doubt about the doctoral

candidate's equal participation in the collective works, and that the dissertation is his own work, under the guidance of his scientific advisor. I am convinced that the doctoral candidate's work has become known to the scientific community, as the publications are included in peer-reviewed proceedings of national and international scientific conferences.

The doctoral candidate has also presented:

A/ Three awards from:

- Lachezar Tsotsorkov Foundation
- Ivan Evstratiev Geshov Award of the Bulgarian Academy of Sciences for young scientists under 30 years old
- Eureka Foundation for young inventor for 2023

B/ List of participation in three projects related to the dissertation topic.

C/ Annual Report of the Bulgarian Academy of Sciences for 2022, "Particle Emission under Uniaxial Pressure of Solid Structures," pp. 43-44.

I have not identified any plagiarism in the scientific works of the doctoral candidate, in accordance with Article 24, Paragraph 5 of the Law on the Development of Academic Staff in the Republic of Bulgaria (ZRAS RB).

I declare that I am not a related person to the doctoral candidate within the meaning of Paragraph 1, Item 5 of the Additional Provisions of the ZRAS RB.

I know M.Sc. Eng. Martin Ralchev as an initiative-taking, energetic, and hardworking young scientist. He possesses enviable theoretical preparation and is capable of designing and organizing independent scientific research. Correct interpretation of the obtained results is not a problem for him.

8. Evaluation of the Abstract:

The abstract is formatted according to the requirements. It is entirely based on the dissertation, with no suggestions or data not treated or discussed in the dissertation. The contributions and conclusions in the abstract are identical to those in the main material. An English summary is also presented.

9. Opinions, Recommendations, and Remarks:

The author has done significant work in detailing the research results. The dissertation is well-formatted, both structurally and stylistically. I have not noticed any substantial errors. I have noted some non-essential editorial recommendations on the dissertation and abstract manuscripts, which the doctoral candidate has addressed in the final version.

Due to the multifaceted applied effect of particle generation under uniaxial deformations in inhomogeneous systems, I recommend the intensive continuation of the doctoral candidate's work on constructing innovative robotic platforms, sensor devices, and new-generation technologies.

10. Conclusion:

The goal of the dissertation and its main tasks have been successfully achieved. Positive results have been obtained, forming five scientific and applied contributions. The dissertation is written in a good style, sufficiently logical, consistent, and well-structured. The results of the dissertation are applicable in engineering practice and have been popularized through three publications, one patent, and two patent applications.

I positively evaluate the conducted training with a very high credit result. The legal requirements have been met, both in terms of the dissertation and for improving the educational preparation and demonstrating the doctoral candidate's ability for independent scientific work. Therefore, I propose to the esteemed Scientific Jury to award MSc. Eng. Martin Lachezarov Ralchev the educational and scientific degree "Doctor" in professional field *5.2 "Electrical Engineering, Electronics, and Automation"*.

Sofia, 20.06.2024

Reviewer:

Prof. Dr. Eng. A. Ivanov