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
Topic of the dissertation: "EMISSION AND SENSORY REGISTRATION OF MICROPARTICLES IN INHOMOGENEOUS STRUCTURES UNDER UNIAXIAL DEFORMATIONS" in professional direction 5.2. "Electrical engineering, electronics, automation", scientific specialty "Elements and devices of automation and computer technology"
Reviewer: Prof. Dr. Eng. Nikola Vichev Kolev, DSci.

## 1. Relevance of the problem developed in the dissertation in scientific and scientific-applied terms:

The creation of new sensor methods and technologies for diagnosing the state of rock formations and concrete composites under uniaxial loads are of strategic importance. The relevance of the topic of the dissertation work of Eng. Martin Ralchev is beyond doubt, because society requires the active development of methods and sensors for objective evaluation in the registration of microparticles in inhomogeneous structures under uniaxial deformations.

The dissertation student Martin Ralchev was born in 1995 and completed a bachelor's and master's courses in electrical engineering at the Electrical Faculty of the Technical University, Sofia in 2020.

He worked first at the Technical University, and then as a research assistant at the Institute of Robotics at the BAS. He was immediately enrolled in part-time doctoral studies at the Institute under the supervision of Prof. Dr. Eng. Sia Lozanova. Eng. Ralchev was expelled from the doctoral studies with the right to defense on 29.04.2024.

The dissertation project was examined and a decision was made to open a defense procedure.

Over the years, Eng. Ralchev has been honored with a number of awards for his active participation in scientific projects of the institute, including the award of the Eureka Foundation for a young scientist-inventor for the year 2023.

## 2. Set goals and tasks:

The goal pursued by the dissertation student is to establish the emission of microparticles from the surface of inhomogeneous rock systems from the territory of the country and to propose an innovative integral method for assessing the stress state of these inhomogeneous structures under uniaxial loads.

The main tasks, systematized, include: analysis of the rock samples under uniaxial deformation and the associated formation of finely dispersed mineral particles in the nano- and micro-size range, and the variation of their intensity depending on the load value was clarified; determination of the influence of the type of rocks from different regions of Bulgaria on the intensity and composition of the formed micro- and nanoparticles; establishment of the dependencies between the emission of particles, the level of deformation

of the rock structures, the area of the samples, etc., design, implementation and research of innovative engineering solutions for obtaining integral information about the state of rock systems.

Solving these tasks will lead to the development of innovative methods and systems for predicting and managing the risks of destruction in the conditions of seismic activity, in the mining industry, for assessing the condition of dam walls, etc.

**3. Degree of knowledge of the state of the problem and of the literary material:**

The review of the list of literature used in the dissertation, including 71 titles, of which 29 in Cyrillic and 42 - in Latin, shows that the dissertation student knows the publications in the field of sensor electronics, modeling and measurement technique. He shows good literary awareness by correctly citing Bulgarian and foreign sources to justify the chosen development approach. The dissertation research was carried out at the Institute of Robotics at the BAS and the National Competence Center "Quantum Communication, Intelligent Security Systems and Risk Management" - Quasar at the IR.

**4. Correspondence of the chosen research methodology with the set goals and objectives:**

The dissertation student methodically correctly chose to analyze existing methods for evaluating and monitoring the stress-deformed state of rock massifs, and the focus is on different mechanisms for the interpretation of stresses and deformations in inhomogeneous systems. He has considered methods of forming specimens and laboratory apparatus on which to carry out uniaxial deformation of rock structures. The dissertation student proposes to directly observe the processes that develop in the samples under pressure, including the formation of finely dispersed mineral particles, and the experimental studies in a laboratory environment are based on laser spectrometry. This approach makes it possible to accurately measure emissions from finely dispersed particles simultaneously in different size ranges, providing more detailed information about their structure and composition. The analysis of the processes of deformation and destruction of rock formations helps to clarify the mechanisms of destruction of test bodies from different types of rocks in Bulgaria.

An integral sensor method and a system for registering the deformation state of rock massifs were created by the dissertation student, and a vertical drilling and sensor system for monitoring the predestructive state of rock massifs was proposed.

I support the doctoral student's research approach to solving the set tasks by creating an experimental set-up for uniaxial loading of the samples and a sensor system for registering microparticles from the samples during their uniaxial deformations. Methods for sensory registration of the powdered microparticles from the rock and concrete samples have been mastered, applied and improved. The application and improvement of these methods enrich the knowledge and experience of the dissertation student and represent a contribution of educational importance.

## 5. Brief analytical description of the dissertation work:

The dissertation is in a volume of 114 pages, including an introduction, five chapters, scientific and applied contributions and used literature.

It meets the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria and the Rules for it, as well as the Rules of the BAS for a dissertation for the educational and scientific degree "Doctor".

In the first chapter "State of the problem" a literature review and analysis of the state of research on evaluation of rock formations and methods for studying the internal stress of rock massifs (seismic methods, methods by probing and surface profiling, ultrasonic and electrical methods and radiometric method. Known methods and systems for recording the deformation state of the rocks causing microparticle emissions are discussed. In the scope of the studied phenomena, methods for the analysis of the rock samples are considered.

The classification of genetic rock types in geology is based on the origin and processes that led to their formation. Rocks are grouped into three main categories: igneous, sedimentary, and metamorphic, each characterized by unique genetic types and formation processes.

This chapter also provides an overview of the industrial significance of systems for studying the failure of concrete under uniaxial loading of structures. The tasks to be performed during the development of the dissertation are displayed.

The second chapter "Formation of microparticles during loading of rock structures" is devoted to the analysis of the genetic types of rocks and assessment of the inhomogeneity of rock formations. The dissertation research is structured in such a way as to achieve the necessary solutions to the tasks set in the dissertation.

A theoretical analysis is made, followed by experimental studies, graphical and mathematical processing of the obtained results. According to the dissertation student, in recent decades the study of deformation-destructive processes in materials is particularly relevant, with special attention being paid to the behavior of cylindrical cavities under various loads, and not least in the study of seismic activity.

The dissertation emphasizes that the existing methods for studying the internal stress and state of rock massifs and concrete are diverse and each technology offers advantages for different applications and brings disadvantages in the assessment of the state of the studied samples. In recent decades, the study of deformation-destructive processes in materials has become particularly relevant, with special attention being paid to the behavior of cylindrical cavities under various loads, and last but not least, to the study of seismic activity.

These studies are of primary importance as they have wide applications in geotechnics, mining, seismic, structural engineering and materials design. As a result of the research in chapter two, the deformation-destructive processes in cylindrical cavities were modeled and the formation of particles from their surface was studied. The distribution of stresses around the cylindrical formations and the dynamics of separation of the fractions have been

identified. It has been proven that the cylindrical cavities simultaneously act as macrodisruptions in the rock structure and as amplifiers of the deformation impact, influencing the generation process.

In the third chapter, "Experimental set-up for the study of dynamic processes in inhomogeneous structures", the dissertation claims that obtaining information about the processes in rock structures under uniaxial loading requires specific experimental methods, sensor devices and equipment.

In this chapter, dissertation student presents an original sensor system he developed, used in experiments to study the internal stress and condition of rock mass and concrete, which are diverse. In order to model the stress in a homogeneous and isotropic mass, which is exposed to a plane stress state, the relations established by the theory of elasticity are used. The dissertation substantiates the experimental methods for the detection of aerosol particles under uniaxial pressure and emphasizes that reproducible and highly accurate metrology of the fractions released from the sample surface as a result of the uniaxial impact is required.

In the fourth chapter "Experimental results" first of all an explanation is given about the origin of the rock samples and it is noted that a great variety of rock formations are observed in Bulgaria, from which several samples were selected for the experiments: gray granite, granite, gray marble, dolomite, rhyolite and limestone.

Samples in the form of cubes, cylinders and parallelepipeds were prepared from these samples. In order to achieve reproducibility and comparative analysis, the particles should be generated from an isolated volume created inside the test specimen itself.

This volume is formed by a through cylindrical cavity centrally located in the sample and the emission of microparticles is recorded directly from inside the sample. Based on the results of the experiments, it is concluded that the greater the uniaxial pressure on the sample, the greater the amount microparticles are generated from the isolated volume created inside the specimen itself and the particle emission is recorded directly. The innovative experimental bench set up for the purposes of the dissertation research has made it possible to carry out experiments with high precision in controlled laboratory conditions, which is essential for elucidating the processes related to the emission of mineral particles in uniaxially loaded rock samples and concretes. The technical solutions of the sensor system, specially organized for the experiments with the samples and for the registration of the separated microparticles from the samples during the uniaxial pressure on the samples, are interesting.

The analysis of the data from the experiments reveals regularities in the behavior of rock materials under the influence of compressive pressure, which illustrates that when compressive stress approaches high values, a significant increase in particle emissions is observed in all size ranges. This can be taken as an indicator of the beginning of structural changes in the materials, which lead to a higher degree of fragmentation and, accordingly, to an increase in the number of emitted particles. In the dissertation it is emphasized that the study of concrete samples shows that structures subjected to cyclic loading show signs of weakening of their strength characteristics. The sharp increase in particle emission intensity

serves as an indicator of their impending macrodestruction, which was identified in the concrete specimens, highlighting the importance of this approach for predicting the structural resistance of different types of concrete.

In the future, the doctoral student plans to expand the scope of sensor research to other types of building materials, for which particle emission will successfully determine important parameters, which will expand knowledge about the dynamics of their deformation processes. As is known, soils in the distant past were structurally formed by the weathering of rocks from the earth's surface, and the more rock microparticles accumulated, the faster the different soil types formed and the greater the soil fertility. This gives me reason to think that the dissertation research will also be useful for soil specialists to guess the age of different soils.

In the fifth chapter "On the origin of the emission effect and prospects for its upgrading" the applicability of the obtained results is discussed, emphasizing the reproducibility of the newly discovered regularity in the same rock structures obtained from different areas of the country. The dissertation attempts to explain the generation of particles in inhomogeneous solid structures under uniaxial impact at different scales. The discussion of the emission effect requires clarification of the micro- and nano-level processes, which are the primary cause of the generation of the mineral fractions during uniaxial deformations in the disordered systems - rocks and concretes. It was established by the dissertation student that rock and ore samples under high deformations emit electromagnetic waves in a wide frequency range. The origin of this process is related to the displacement of dislocations containing electric charges in the field of high mechanical stresses. Also, the oscillatory movement of the charged ends of the cracks and the interaction of electric charges at the ends of the cracks lead to the appearance of currents and the formation of electromagnetic fields with a vortex structure. The intensity of the emission is related to the value of the acting external loads, in which local microregions of disintegration are formed in the samples of geomaterials in the stage of pre-destructive deformation. It was established that the maximum amount of particles is released precisely at the moment of increasing the load close to critical values. The process is related to the time of redistribution of internal stresses, resulting in the detachment of particles from the surface of rock structures. The change in the position of the electrostatic bonds is irreversible, which modifies the arrangement between the positively and negatively charged groups of particles. With rocks, restoration of the state after deformation is impossible. The process is related to the time of redistribution of internal stresses, resulting in the detachment of particles from the surface of rock structures. According to the dissertation, nano- and microdefects in the volume or on the surface of the sample form a "shell" of randomly dislocated electrically charged particles. The released potential energy further polarizes neighboring molecular groups. The final result of the deformation of the rock is the emission, i.e. generation of particles with a corresponding spectral composition that is experimentally observed. They initially leave the subsurface areas of the specimen. The most important thing in this quality model is its so-called "one-way", i.e. irreversible exhaustion of the generation process, which the reviewer shares.

Based on the obtained results, the dissertation student constructed a system for registering destructive conditions in the rock massifs in real conditions. The study of the emission

phenomenon offers opportunities for upgrading both in the field of studying the physics of the destruction processes of various materials, as well as in applied fields. Its application in seismology to predict earthquakes, as well as in the mining industry to control the risk of dynamic manifestations of pressure in rock structures, is particularly significant.

**6. Contributions of the dissertation work:**

In the dissertation, a new scientific problem in the field of sensors was established and investigated - recording the emission of nano- and microparticles in inhomogeneous structures under uniaxial deformations.

I support the contributions formulated by the dissertation student, which are related to:

1. A previously unknown regularity in solid inhomogeneous systems - rocks and concretes - was experimentally established, which consists in the generation of particles under the influence of high uniaxial deformations, in which it was proven that the quantities of emitted mineral microfractions in the range 0.3 μm - 5.0 μm are reproducible for a specific type of rock in the different mountain ranges.

2. According to an original methodology, an experimental set-up in four variants was designed, implemented and tested, equipped with sensor devices, measuring with high accuracy the characteristics of the released microparticles depending on the geometric shape of the rock samples under uniaxial pressure.

3. The functional dependence on external factors has been determined in the case of a proposed phenomenological and physicochemical interpretation of the new regularity for the generation of particles, as in the case of deformation, their intensity and size depend on the type of rocks supplied from different regions in the country.

4. It was found that at levels of deformation pressure of the rock structures up to the limit of their disintegration, there is a sharp, in a first approximation, exponential growth of the particles in all their size ranges, as their quantity is directly proportional to the generating surface of the samples, as the intensity of emission process is justified to serve as an indicator for predicting their destruction.

5. An integral method and system for dynamic determination of the stress-strain state of rock massifs has been proposed and developed.

6. Permanent monitoring of microparticles is proposed to serve for early disclosure of pre-accident and emergency situations in critical infrastructure with applicability in: seismically active areas for detecting the folding of tectonic plates; mining industry; the construction of tall buildings and their pre-destructive conditions; landslide prevention; controlling the state of dam walls, bridges, viaducts, etc.

7. An integral sensor method and system for registering the deformation state of the rock massifs was formulated and developed. A vertical borehole and a sensor device for monitoring predestructive states of rock massifs is proposed.

**7. Assessment of the degree of personal participation of the dissertation student in the contributions:**

I do not know Martin Ralchev personally, but from his documents I understand that he completed his doctoral studies with excellent grades and recommendations, and was actively involved in the implementation of scientific projects. I am under the impression that the proposed approaches and methods, as well as the obtained results and experimental data on the dissertation, are the personal work of the dissertation student and are reliable. The methods learned and applied in the research, and the sensor systems created in the dissertation are a good attestation for the dissertation student and represent high-quality elements of the educational and scientific parts of the "doctor" degree.

**8. Evaluation of publications on the dissertation work:**

I carefully read the scientific works on the dissertation, which are 3 in number, in two of which Ralchev is an independent author and three patents, and I accept that they reflect the main parts of the development. The posts are well-reasoned, analytical and complete. In the publications and patents, Eng. Ralchev wrote in co-authorship with the scientific supervisor and with established scientists from the Institute of Robotics, which is a reason to consider his teamwork as successful. His contribution to the preparation of the publications is clearly distinguished. From what I have read in the dissertation and the publications, I appreciate that the dissertation student, still young, has mastered the theoretical analysis and experiments on the developments, and the presentation of the results in several scientific forums proves his active presence in the scientific life of the BAS. It can be assumed that the results of the dissertation research are known to the scientific community at home and abroad, as the publications are included in peer-reviewed proceedings of national and international scientific conferences.

I note that the dissertation student has not proven plagiarism in his scientific works in accordance with the statutory procedure (Art. 24. para. 5 of the ZRASRB).

I have no publications in common with the dissertation student and I am not a person related to him in the sense of paragraph 1, item 5 of the Additional Provisions of the ZRASRB.

**9. Use of the results of the dissertation work in scientific practice:**

Sensory registration of nano- and micro-particles, the metrological method proposed for the first time in sensorics at the basis of the experimental study of concrete and rocks using micro- and nano-technologies represents a new approach in the use of sensorics for the registration of nano- and micro-particles of sputtering under uniaxial compression. The approach is express, implementable instrumentally, and suitable for robotic quality control in micro- and nano-electronics.

Results of the dissertation research were used in the successfully completed scientific project "Bulgarian National Plan for Quantum Communication Infrastructure - DIGITAL-2021-QCI-01" under a contract between the Directorate General "Communication Networks, Content and Technologies" of the European Commission and IR.

The results of the dissertation developments can be used in innovative solutions with multifunctional applicability related to the study of rocks and composite materials.

**10. Assessment of the compliance of the author's reference with the requirements for its preparation:**

The abstract complies with the requirements of the Volume Regulations, reflects the content of the dissertation and presents its contributing elements.

**11. Opinions, recommendations and notes:**

1. The cited literature is not arranged according to the requirements of the BDS. First - the literature in Cyrillic and then - that in Latin.

2. On page 34 of the dissertation it is written "pesticides - to increase yields", which is incorrect. Pesticides are chemical reagents for the destruction of weeds, in which conditions are created for better development of crops.

3. There are spelling errors in the text of the dissertation.

The results obtained and the usefulness of the development allow me to give a positive review of the dissertation defense procedure, regardless of my critical remarks.

**12. CONCLUSION:**

**I positively evaluate the results of the development of the dissertation work with the author M.Sc. Eng. Martin Lachezarov Ralchev on the topic: "Emission and sensor registration of microparticles in inhomogeneous structures under uniaxial deformations" in professional direction 5.2. "Electrical engineering, electronics and automation", scientific specialty "Elements and devices of automation and computing technology" to obtain the educational and scientific degree "Doctor" and I propose to the Scientific Jury, appointed by order No. 32 of 15.05.2024 of the Director of the Institute of Robotics at BAS to award the educational and scientific degree "Doctor" to Martnn Lachezarov Ralchev in the scientific specialty "Elements and Devices of automation and computer technology".**

Sofia

12.06. 2024

Signature:

Prof. Dr. Eng. Nikola Vichev Kolev, Dr. Sci.