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**REVIEW**

official opponent Maksym BONDARENKO

on the dissertation thesis by **Denys KATAIEV**

"Software and information complex for improving the accuracy of measurements of
geometric parameters of power equipment parts based on a neural network"

presented for the degree of Doctor of Philosophy

in the field of knowledge 17 "Electronics, Automation and Electronic Communications"

in the specialty 175 "Information and Measuring Technologies"

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### 1. Relevance of the dissertation topic

The energy industry is one of the key areas for ensuring the stable functioning of modern society. Reliability, efficiency, and safety of power equipment, such as turbines, generators, boilers, contingent upon manufacturing accuracy and compliance of parts with standards and technical requirements. Deviation of geometric parameters can lead to a decrease in the equipment performance, its premature wear, significant repair costs, and, in critical cases, to emergency situations with catastrophic consequences for production and the environment.

Modern information and measurement systems facilitate highly accurate, fast, and automated control processes. However, these systems pose a number of limitations, for instance, insufficient ability to adapt to external destabilizing factors (vibrations, thermal deformations, inertial effects).

The relevance of the dissertation topic stems from the necessity to overcome existing limitations. It centers on the development of a software and information system incorporating an integrated neural network, whose implementation within a coordinate measuring arm-based information and measurement system will effectively mitigate the influence of external destabilizing factors, thereby significantly enhancing the accuracy of geometric parameter measurements for power equipment components.

### 2. Connection of work with scientific programs, projects or plans

The dissertation is related to the research topic: "Development of methods and means for monitoring the state of the environment of energy facilities based on wireless sensor networks" (0123U100127, 2023–2027).

### 3. Assessment of the validity, reliability and novelty of the scientific results presented in the dissertation

The validity and reliability of the scientific provisions and conclusions of Denys KATAIEV'S dissertation are attested by the comparative analysis of literature sources, including 143 titles related to the dissertation topic, mathematical and logical rigor in selecting approaches and constructing models, accurate setting and solving research

problems, amply tested methods for analyzing the risks of complex systems and methods of multi-criteria decision-making.

The validity of the conclusions and the results of the dissertation thesis are confirmed by the results of computer modeling and testify to the high efficiency of the proposed methods and tools. The scientific results obtained by Denys KATAIEV correspond to the objectives of research and have been approbated at scientific and technical conferences and seminars.

The high level of the results obtained has been confirmed by their implementation in the practice of controlling measurements of geometric parameters of components of ECO LUX LLC and AVA TEK LLC.

The dissertation thesis formulates a clear scientific objective: the development of a software and information system based on a neural network, aimed at enhancing the accuracy of geometric parameter measurements for power equipment components. This system, integrated into an information and measurement system, has been designed to compensate for destabilizing factors, adapt to fluctuating operational conditions, and maintain high performance under demanding industrial environments. Thus, this dissertation thesis demonstrates the full execution of its scientific objective, and the applicant has clearly mastered the methodology of scientific activity.

### 4. Assessment of the dissertation content, completion, and adherence to the principles of academic integrity

In terms of its content, the dissertation by Denys KATAIEV fully complies with the standard of higher education in the specialty 175 "Information and Measuring Technologies" and the areas of research in accordance with the academic program "Information and Measuring Technologies in the Energy Sector".

The dissertation is a completed research and represents the applicant's personal contribution to the field of improving the efficiency of distribution network operation modes.

After considering the similarity report, we concluded that the dissertation thesis by Denys KATAIEV is the result of the dissertation candidate's independent research where elements of falsification, compilation, fabrication, plagiarism or borrowing are absent. The ideas, results and excerpts by other authors are presented as proper references to the relevant sources.

### 5. Assessment of the language, structure, and content of the dissertation thesis

The dissertation thesis is performed in English, compiled and formatted in compliance with the requirements of the Order No. 40 of the Ministry of Education and Science of Ukraine dated January 12, 2017 "On Approval of the Requirements for the Preparation of the Dissertation". The thesis is distinguished by a logical, clearly

structured, and coherent presentation of the material, complemented by the appropriate use of professional scientific and technical terminology that aligns with contemporary standards in the field of information and measurement technologies. The author demonstrates a commendable level of linguistic competence, with minimal grammatical or stylistic errors, reflecting the high editorial quality of the dissertation.

Structurally, the thesis comprises an introduction, five chapters, general conclusions, a bibliography listing 143 sources, and supplementary appendices. The total length of the work spans 157 pages and includes 53 figures and 16 tables. The substantial use of illustrative material enhances the comprehension of complex technical concepts and contributes to the effective presentation of the research findings.

**In the introduction**, the author substantiates in detail the relevance of the research topic, which hinges on the necessity to enhance the accuracy of geometric parameter measurements for power equipment parts by developing a software and information complex with an integrated neural network. The introduction also contains information about the approbation of the thesis findings at conferences and about the candidate's personal contribution to the research, supplemented by the list of the candidate's research publications.

**Chapter One** focuses on the analysis of modern coordinate measuring arm-based methods for improving measurement accuracy. In the first place, a thorough insight into the sources of kinematic and non-kinematic errors has been conducted. The chapter reviews in great detail the problems of compensating for the influence of destabilizing factors, in particular, thermal deformations, backlash in connections and encoder hardware errors. The author has established that most modern approaches do not provide adequate compensation for non-kinematic errors due to their complex nature, which forms the basis for the integration of neural networks into the composition of information and measurement systems. The author has clearly formulated the research objective, thus determining further research.

**Chapter Two** develops an effective kinematic model of the coordinate measuring arm based on the Denavit-Hartenberg parameters. The chapter offers a detailed mathematical description of the proposed model, accompanied by a combined calibration method that accounts for various sources of error. Additionally, a technique for compensating residual kinematic errors based on a single-point correction model is developed, enabling its practical implementation.

**Chapter Three** serves as the core of the dissertation, focusing on the development of a software and information complex for a coordinate measuring arm integrated with a neural network. It presents a structural diagram of the designed system, thoroughly justifies the selection of the neural network architecture, and outlines the criteria guiding its development. Particular emphasis is placed on the software tools employed for the implementation of the neural network, in particular, Python programming language relying on popular modern libraries PyTorch, NumPy, SciPy, scikit-learn,

etc. The choice of these software tools is fully justified given the current trends in the development of machine learning.

**Chapter Four** contains a thorough description of the developed algorithms for preparing data to train a neural network. The author has developed and proposed methods for generating synthetic datasets that effectively simulate the impact of external destabilizing factors, such as temperature deformations, encoder errors and backlash in connections. The results obtained in this chapter are significant for ensuring efficient practical application of the developed system.

**Chapter Five** is of an experimental nature, whereby the author presents the experimental study results of the developed software and information complex with an integrated neural network. A thorough analysis of the influence of the selected activation functions and training parameters on the accuracy of the neural network has been studied in this chapter. The experimental results demonstrate a significant increase in the accuracy of measurements and attest to the efficiency of the proposed approach to compensate for non-kinematic errors.

The **conclusions** effectively summarize the study's outcomes and clearly articulate the dissertation's scientific novelty, which is substantiated by experimental validation. The practical significance of the research is demonstrated through its successful implementation within industrial enterprises, as confirmed by corresponding acts of application. The appendices provide comprehensive specifications of the developed models, algorithms, and the structural framework of the software package, reinforcing the completeness and credibility of the reported results.

**General assessment of the dissertation**: Overall, the dissertation represents a thorough and well-executed research. The findings exhibit notable scientific innovation and substantial practical relevance. Conducted with a high degree of methodological, theoretical, and experimental rigor, the work aligns with contemporary academic standards and the formal requirements of dissertation research. In light of the dissertation's achievements, I consider the author deserving of the Doctor of Philosophy degree.

## 6. Scientific significance and practical value

The proposed dissertation has for the first time yielded the following scientific results, which determine its novelty:

1. A universal calibration method has been proposed, integrating three calibration standards into a single procedure. This approach enables the compensation of systematic errors in surface sensing, facilitates the assessment of the coordinate measuring arm's stability in reproducing spatial reference points, and determines the parameters related to its linear movement reproducibility.

2. A compensation technique for residual kinematic error has been developed based on a single-point correction model. This method achieves a fourfold reduction in the kinematic component of the residual error.

3. Advancements in neural network learning theory allow for the automatic adaptation to varying measurement conditions and effective compensation for destabilizing factors. As a result, the non-kinematic component of the residual error was reduced by a factor of six.

The practical significance of the results obtained in the dissertation arise from the development of a software and information complex that allows for enhancing the accuracy of geometric parameter measurements for power equipment parts under challenging production conditions. The key aspects of the dissertation's practical value embrace:

1. The structure of the information and measurement system has been proposed, which relies on integrated information and measurement systems, and a software and information complex with an integrated neural network to increase the accuracy of measurements for geometric parameters of power equipment parts.

2. A software and information complex with an integrated neural network has been developed, which allows for calibrating, processing data, training the neural network, and automating the processes of compensating for destabilizing factors.

3. 432 modifications for neural networks were developed to analyze current data of measuring geometric parameters of power equipment components, which achieves compensating both for variable measurement conditions and destabilizing impacts.

### 7. Publication of the results of the dissertation thesis

The research findings of Denys KATAIEV's dissertation are featured in 6 scientific publications, including: 5 articles in research journals included in the list of scientific professional publications of Ukraine as of the publication date; 1 article in an international edition; 1 utility model patent. Additionally, the dissertation findings have been probated at three scientific professional conferences.

The candidate's publications demonstrate a high scientific standard and have undergone peer review and plagiarism checks in accordance with the policies of the respective publishing houses. The candidate's personal contribution to these works is significant, reflecting a strong individual involvement in the research and writing process. The publications comprehensively encompass all key scientific findings presented in the dissertation. Accordingly, the scientific results outlined in the dissertation are fully substantiated by the candidate's published works.

## 8. Disadvantages and comments on the dissertation

Overall, the dissertation is performed at a high scientific and technical level. Nonetheless, I would like to make several comments and recommendations that may improve the quality of the dissertation:

8.1. Chapter One of the dissertation (p. 25, p. 28) contains tables (Table 1.1, Table 1.2) describing the factors of kinematic and non-kinematic errors. However, no references to specific literature sources are specified, which, if they were present, would significantly fortify the author's argumentation.

8.2. When considering mathematical models of error compensation (pp. 27-32), the author offers no specific numerical examples of error calculations. The examples could serve for a better assessment of the practical efficiency of the proposed approaches.

8.3. Chapter Two (pp. 38-42) describes in detail a kinematic model based on Denavit-Hartenberg parameters, at the same time lacking graphic materials (e.g., diagrams or 3D rendering) that would greatly facilitate the perception of the proposed model.

8.4. Chapter Three (Clause 3.3, pp. 76-80) indicates the use of Python and the libraries PyTorch, NumPy, SciPy, etc., for the development of the software package, without mentioning technical characteristics of the hardware deployed for neural network training, which is important for evaluating the speed and scalability of the system.

8.5. Chapter Four (clause 4.1, pp. 83-89) describes methods for generating synthetic data for a neural network. Here, a comparative analysis of the obtained synthetic data with experimentally obtained real data could have further confirmed the validity of the proposed approaches.

8.6. In the experimental section of Chapter Five (pp. 105-125), the graphs that illustrate the dynamics of the neural network training process (for example, the dependence of training and testing errors) could have been presented in more detail, which would enhance the reader's comprehension of the efficiency of training the network.

8.7. Throughout the dissertation, a section designated to clearly define the limitations of the methods used or outline specific areas of future research could not be located. Otherwise, such a section could significantly expand the prospects of the research.

I believe that the above remarks should not be considered critical and do not mitigate the overall positive assessment of the dissertation, its scientific novelty and practical significance. However, considering the above remarks will significantly increase the quality and value of further research.

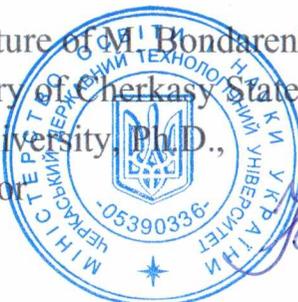## 9. Conclusion on the dissertation work

I believe that the dissertation of the PhD candidate Denys KATAIEV on the topic "Software and information complex for improving the accuracy of measurements of geometric parameters of power equipment parts based on a neural network" is performed at a high scientific level, does not violate the principles of academic integrity and is a completed scientific research, the totality of theoretical and practical results of which solves a scientific problem that is essential for the field of knowledge 17 "Electronics, Automation and Electronic Communication". The dissertation fully complies in terms of relevance, practical value and scientific novelty with the requirements of the current legislation of Ukraine, which are provided for in paragraphs 6–9 of the "Procedure for awarding the degree of Doctor of Philosophy and cancellation of the decision of the one-time specialized academic council of a higher education institution, scientific institution on awarding the degree of Doctor of Philosophy", approved by the Resolution of the Cabinet of Ministers of Ukraine dated January 12, 2022 No. 44.
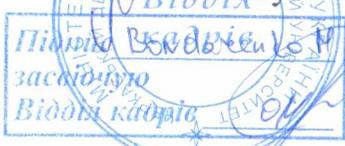
The applicant Denys KATAIEV deserves to be awarded the degree of Doctor of Philosophy in the field of knowledge 17 "Electronics, Automation and Electronic Communications" in the specialty 175 "Information and Measurement Technologies".

**Official opponent**:

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I certify the signature of M. Bondarenko:
Scientific Secretary of Cherkasy State
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