REVIEW

on the dissertation work for the acquisition of educational and scientific degree "Doctor" in professional direction 5.2. Electrical engineering, electronics and automation, Doctoral programme: "Microelectronics"

Author of the dissertation work: mag. Eng. RUMYANA ANGELOVA STOYANOVA
Topic of the dissertation work: "DEVELOPMENT OF INNOVATIVE METHODS AND MECHANISMS FOR ENERGY PIEZOHARVESTERS"
Scientific leaders:
Associate professor. Eng. Velimira Dimitrov Todorov PhD
prof. Eng. Anatoly Trifonov Alexandrov PhD
Reviewer: Prof. Eng. Ivan Borisov Evstatiev PhD, Ruse University "Angel Kanchev" – Ruse

1. GENERAL DESCRIPTION OF THE SUBMITTED MATERIALS

A thesis file of **159** pages is provided, arranged in **4** chapters, also including, an introduction, an author's view of scientific and applied contributions, a list of publications on the dissertation work and a literature reference. The presented list of publications on dissertation work contains **5** titles.

The list of analysed literary sources contains **200** publications. Most of the publications have an email address and **DOI,** allowing easy access to them.

There is also a list of abbreviations and designations used a list of **77** tables and a list of **180** figures.

I believe that the materials provided on the dissertation work meet the generally accepted requirements.

2. TOPIC AND TOPICALITY OF THE DISSERTATION WORK

The topic of the thesis is related to the field of renewable energy, researching and developing non-conventional sources of electrical energy that provide power to devices and systems with low consumption. It is noteworthy that these energy sources use principles and effects that allow energy production characterized by the use of difference in energy levels, vibrations and other effects that do not pollute the environment. This type of power sources allow power supply to devices and systems without the use of batteries and conventional energy.

This direction of research is particularly relevant, considering the trend of decreasing energy consumption by modern electronic devices and systems.

The aim of the dissertation is creation and optimization of existing models, as well as mathematical modelling of piezoelectric harvesters of vibration and compression type.

Taking into account the above, as well as the set goal, decided in the main tasks of the dissertation work, we can confidently say that the topic and purpose of the dissertation work are extremely relevant.

3. DEGREE OF KNOWLEDGE OF THE STATE OF THE PROBLEM AND CREATIVE INTERPRETATION OF THE LITERARY MATERIAL

To achieve the goal, the dissertant has set **5** tasks, successively solved in the individual chapters of the dissertation.

The literature research conducted (chapter 1) and the analysis done in it show an excellent knowledge of the subject. The literary titles are **200** and correspond to the subject's subject. Of the literary sources, **3** are in Cyrillic and **197** in Latin, of which **55** are presented with links.

Because of the analysis of the literature sources, the goal of the dissertation work is fixed and the tasks for achieving this goal are set.

From the provided material, it can be said that the doctoral student knows the state of the problem very well and has creatively interpreted the information from the analysis of the literary sources.

4. RESEARCH METHODOLOGY

The methodology of the research has the following sequence – analysis of the state of the problem, analysis of existing models, improvement and development of new mathematical models, verification of the models and their parameters, simulation research with models.

I believe that the chosen research methodology corresponds to the set goal and tasks of the dissertation work.

5. BRIEF ANALYTICAL DESCRIPTION OF THE DISSERTATION WORK

The presented work has a volume of **159** pages. The main material contains **4** chapters. Also presented are analysis and conclusions, the dissertator's view of the contributions of the dissertation work, the publications of the work (**5** in number) and the literature reference. The literature reference consists of **200** sources. The dissertation contains **184** figures, **76** tables and **177** formulas.

In the first chapter, the dissertation has examined and analysed the current state of energy harvesters and their applications.

Methods for generating electrical energy have been analysed. Devices for extracting energy from external sources such as solar energy; thermal energy; wind energy; energy extracted from salinity gradient; kinetic energy, radio wave background, etc. have been studied. The purpose of these devices is to power wireless stand-alone devices or wireless sensor networks. This type of energy source is known as energy harvesting.

The advantages and disadvantages of different methods are analysed.

The **chapter** ends with the formation of the purpose and tasks of the dissertation work.

The second chapter is entitled "Mathematical modelling of piezoelectric harvesters of vibration and compression type".

A mathematical model was proposed to help estimate the amount of energy that can be extracted from the proposed energy-generating device. For this purpose, the basic properties of the materials and the geometric dimensions of piezoelectric harvesters were determined. Models of single-layer, bimorphic and compression piezoelectric harvester were analysed and studied, using private differential equations in the MATLAB environment and the finite element method.

The **chapter** ends with conclusions.

The third chapter is entitled “Applied models and simulation of piezoelectric energy vibration and compression harvesters”.

The history and principles of conversion as well as the methods of generating electrical energy from piezoelectric elements are analyzed.

Using mechanical and electrical modelling, a vibrational piezoelectric harvester, a bimorphic piezoelectric harvester and a compression piezoelectric harvester were modelled. The proposed models were refined through extended equivalent schemes aimed at reflecting the real conditions to which the vibrational piezoelectrical harvesters can be subjected.

A model of the design of a compression harvester is proposed. Based on the model, reasonable assumptions are made that changes in the design of the compression harvester will lead to a change in the generated energy of several orders. Under a change of the harvester design, it is assumed the change in the mutual arrangement between the piezoelectric cells, whose parameters remain constant.

A connection between the individual elements of the harvester was proposed based on a reasonable assumption of the operation of the individual piezoelectric elements. The sequential electrical connection of the piezoelectric elements is not suitable because in order to generate a signal for the entire matrix, all the elements must be subjected to mechanical pressure at the same time, which is not real in the proposed configuration. Therefore, parallel electrical connection of the piezoelectric elements was used in the design for further experimental study.

The **chapter** ends with conclusions.

The fourth chapter is “Experimental studies of piezoelectric harvesters of vibration and compression type”.

An experimental installation has been developed for experimental studies of a vibrational piezoelectric converter. Experimental studies of the piezoelectric converter have been conducted to determine how much power can be extracted from it. A vibration stand was used for the studies, through which mechanical vibrations with different frequencies of action are provided.

The experimental studies were conducted with a commercially available piezoelectric harvester of type S233-H5FR-1107XB with a bimorphic structure with sequential layer bonding. An electromechanical shaker was used to induce the external mechanical action.

The first group of experiments was conducted with an inertial mass m=1.13 g with different values of the resistive load (RL) and a change in the frequency range from 119 to 127 Hz. Because of these studies, due to significant deviations for the expected results of the received current, it was decided to use a rectifier bridge for subsequent studies.

Studies were made for different values of the filtering capacitor after the rectification bridge; respectively change of active load and frequency of vibrations of the harvester.

An experimental setup was also created for an experimental study of a compressive piezoelectric path. An experimental study with intermittent impact on a piezoelectric path was conducted. The impact of subjects with different contact surface and mass on a piezoelectrical path was studied. Methodologies were developed for the research.

The chapter ends with analysis and conclusions.

Next are "Analysis and conclusions", where the summary analysis of the dissertation work and the main conclusions are presented, "The view of the doctoral student on the scientific-applied contributions", "List of publications' related to the dissertation and "Literary reference".

The presented material in the dissertation work fully corresponds to the topic "Development of innovative methods and mechanisms for energy piezo harvesters".

I consider that the material also meets the requirements of the Law on the Development of Academic Staff in R. Bulgaria and the Regulations to it, as well as the Regulations of the Technical University Gabrovo for the acquisition of the educational and scientific degree "Doctor".

6. CONTRIBUTIONS TO THE DISSERTATION WORK

I agree with the author about the contributions of the dissertation work. The contributions in the present dissertation work are of a scientifically applied and applied nature.

Scientific and applied contributions

1. On the basis of the examined physical and mathematical principles of operation of piezoelectric harvesters, the consideration of piezoelectric vibrational harvester constructions as a specific particular case of piezoelectric compression harvesters is justified.

2. Advanced equivalent schemes of a vibrating piezoelectric harvester of beam type have been proposed to reflect the real conditions to which this type of construction can be subjected. The elements of the proposed equivalent schemes reflect some of the variable parameters in the operation of this type of harvester

(such as parasitic capacities) as well as the parameters of the external elements to the scheme that affect the operation of the harvester.

3. A model of planar construction of a piezoelectric harvester of compression type was created, which reflects the peculiarities of the elements building this device and is based on the basic principles of resistance of materials for vertical and horizontal stress.

4. Parallel electrical connection between the individual elements of the compression harvester is justified, due to the fact that the sequential electrical connection of elements in this case is not suitable, since in order to generate a signal for the entire matrix, all its elements must be subjected to mechanical pressure simultaneously.

5. As a result of experimental studies, the inclusion of the rectifier in the measurement schemes estimating the amount of energy acquired by the harvesters due to the cost of the obtained experimental results for the obtained variable power was justified and proved. This is explained by the presence of the reactive power compound, which leads to inaccurate counting in the indirect methods of estimating the amount of obtained energy.

6. Two variants of planar design of compressive piezoelectric harvester and methodology for their study are proposed. The research shows that the vertical force with interrupted (impact) character achieves better efficiency compared to the continuous (horizontal-rotational) impact, which is correlated with the model proposed in the third chapter.

These contributions have the character of enriching the existing knowledge related to the extraction of energy from piezoelectric harvesters.

Applied contributions

1. The adequacy of the used measuring schemes of the AV and VA type, as well as the combination between them, was assessed. The results for the permanent part show a high degree of similarity, which proves the correctness of the use of a rectifier in the experimental setup.

2. In connection with the development of compression piezoelectric harvesters, a design was created for more efficient energy collection by reducing the distance between the active elements of the harvester, proven by the experimental studies.

The contributions refer to the application of modern technical means of energy extraction to power systems and devices with low consumption without the use of batteries and conventional energy.

7. PUBLICATIONS ON THE DISSERTATION WORK AND AUTHORSHIP OF THE OBTAINED RESULTS

There are **5** publications on the dissertation work, **3** of which are in **IEEE** conferences and referenced in **Scopus**, **4** are in international scientific conferences.

One of the publications is self-contained. **Four** of the publications are co-authored with a supervisor and other co-authors. In two of them, the doctoral student is in first place.

According to the given material and the publications made on it, I believe that the contributions in the present work are the personal work of the doctoral student, under the guidance of his supervisors.

I accept that the publications reflect the main parts of the development.

The doctoral student meets the scientific criteria for obtaining a scientific degree "doctor".

8. USE THE RESULTS OF THE DISSERTATION WORK IN PRACTICE

I believe that the research in the dissertation work and the results obtained can be used in the development of power supplies for systems and devices with unconventional sources of electricity and low consumption without the use of batteries. Considering the results of the dissertation work and trends of development of modern electronics, I believe that it is extremely relevant and the results of the development will find great application in practice.

9. SELF-ESSAY

The content of the auto abstract corresponds to the content of the dissertation work. The designations of the figures and formulas in the auto abstract match those of the dissertation.

My assessment of the essay is that it meets the generally accepted requirements and accurately reflects the content and contributions of the dissertation work.

10. OPINIONS, RECOMMENDATIONS, REMARKS ON THE DISSERTATION WORK

I do not have any comments on the job.

In addition, to note is the very good structure of the dissertation. Each chapter ends with results and conclusions.

The noted inaccuracies have been provided to the author.

11. PERSONAL IMPRESSIONS

I do not know the PhD student personally. Taking into account the presented dissertation work and the publications related to it, I could say that Mag. Eng. Rumyana Angelova Stoyanova is a scientist with a taste for research work focused on innovations in electronics and microprocessor technology.

Very good impression made by the strong mathematical part - the use of integral and differential equations and matrices for the theoretical part of the development.

12. CONCLUSION

I consider that the presented dissertation thesis meets the requirements of the Law on the Development of Academic Staff in the Republic of Bulgaria and the Procedural Rules of Gabrovo Technical University. **The achieved results** give me reason **to propose to be obtained** the educational and scientific degree **"Doctor" by Mag. Eng. Rumyana Angelova Stoyanova** in the professional field 5.2. Electrical Engineering, Electronics and Automation, Doctoral Program: "Microelectronics".

02.01.2025

Signature: /signature/
/Prof. Eng. Ivan Borisov Evstatiev, PhD/