

National Research University Higher School of Economics

as a manuscript

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**Development of the space radiotechnical devices' reliability calculation
method, considering quality management system influence**

Dissertation summary
for the purpose of obtaining academic degree
Doctor of Philosophy in Engineering

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Moscow – 2021

Relevance

The risks of projects associated with the provision of space communication services every year in the Russian Federation (RF) are increasing, which negatively affects the country profitability in this area. This fact is confirmed by the failures statistics of radiotechnical devices of unmanned automatic spacecraft space equipment during the period of active lifetime of up to 15 years. Due to the regularity of failures, the established "standard reliability budget" is not reached by the end of the active lifetime of both individual types of radiotechnical devices (RTD) and space equipment, and the unmanned automatic spacecraft (UAS) themselves as a whole.

The methods of RTD reliability assessment existing in the Russian Federation confirmed by single indicators of reliability, are reduced to the determination of the failure rate – « λ - characteristics», which depend on the electrical loads of electronic devices (ED), ambient temperature conditions, the severity of operating conditions and other factors. However, the specification of the criteria related to measures to ensure the quality of design and production does not occur. In fact, such a criterion is the "production quality factor", which is designed to take into account the level of requirements for the design and manufacture of RTD. In practice, this coefficient is integral and for the space industry takes the value "0.2", thereby reducing the " λ -characteristic" obtained by calculation for the entire RTD by 5 times, therefore, increasing the probability of failure-free operation. But in fact, the values of single indicators of dependability (reliability) obtained by the calculation method do not reflect the real situation with the statistics of failures obtained from the results of acceptance tests, as well as from the results of exploitation (or active lifetime) and allow us to conclude that the existing methods of their the assessments overestimate the target level of dependability indicators due to the fact that they do not take into account the factors responsible for ensuring dependability, and there are significant shortcomings in the RTD dependability assurance strategy (including the effectiveness of the quality management system of the executing organization).

Thus, a significant contradiction between the theoretical calculation of dependability and experimental (real failures statistics of RTD), as well as the insufficient efficiency of the quality management system (QMS) functioning, gives rise to the relevance of this study for the further development of methods for assessing the dependability of space equipment RTD of UAS, considering the influence of the QMS, i.e. organization management systems in the aggregate, for the implementation of the necessary NTD measures during design and production.

Problem statement

The high error between the calculated data of dependability (reliability) indicators, operational RTD and frequent occurrence of failures before the end of active lifetime is caused by several factors during operations. Such factors include: increasing complexity of space equipment RTD; failures to comply with mandatory measures of normative-technical documentation (NTD) agreed in the technical requirement (TR); poor quality of electronic devices, as well as low efficiency of the enterprise quality management system functioning (in particular, failure to comply with p.4.1 of GOST R ISO 9001-2015) and dependability management system, as a part of QMS. The point is that the existing mathematical models of the particular dependability indicators evaluation do not take these factors into account as coefficients. This fact imposes certain limitations on the accuracy of the values obtained, as the numerical value of the "production quality factor" is regulated by the «ED Dependability Handbook» and assumes the perfect functioning of the QMS with all necessary requirements being fulfilled. However, the failure statistics of the modern spacecraft ED show the opposite, and the highly reliable ones (which have an experimental value of "production quality factor" equal to "0.2") have completed or are completing their designated active life. Therefore, there is an urgent problem of discrepancy between theoretical dependability calculations and experimental data (real ED failure statistics), which requires development of methods to assess dependability of ED, in particular,

electronic modules of the first level (EM1) taking into account multifactorial processes at the design stage.

The purpose and objectives of the study

An increase in the dependability of space equipment RTD of UAS is possible due to the provision of the calculated assessment accuracy of the unit indicators of reliability at the early stages of design.

To achieve this goal, the following scientific tasks were solved in the dissertation research:

1. Review and analysis of the subject area of assessing the dependability of space equipment RTD of UAS, as well as determining the degree of the QMS influence on the quality of the implementation of mandatory measures at the stages of the RTD life cycle with the formulation of the research problem.

2. Development of a mathematical model of the differential "production quality factor", considering the multifactorial nature of the processes and necessary actions of scientific and technical documentation at the stages of the life cycle (LC) "design" and "production" of space equipment RTD.

3. Development of a method for assessing the dependability of space equipment RTD, which consists in step-by-step control of the "design" and "production" stages of the EM1 life cycle and makes it possible to assess the implementation completeness of the necessary measures of technical specifications at each stage.

4. Development of a reliability assurance methodology that allows identifying the achievable level of reliability of space equipment RU by the performing organization based on the results of design and production, as well as having the ability to identify "weak points" of the "design" and "production" stages for timely application of corrective actions required in the task of ensuring the required (target) level of RU reliability.

5. Development of an algorithm and implementation of a software architecture to automate the stages of the method for evaluating the dependability of space equipment RTD.

6. Experimental validation of the dependability assessment method proposed in this dissertation study and implementation of the research results.

Level of development of the problem

The problem of dependability assessment, especially of the particular reliability indicators of the UAS at the designed stage is an actual topic. There are many academic papers on this topic, both in the Russian Federation and in other countries. Significant contributions to the development of this field for our country have been made by the following well-known individuals: I.A. Ushakov, B.A. Gnedenko B.V., Kozlov, G.V. Druzhinin, A.M. Polovko, M.R. Shura-Bura, A.Y. Rezinovsky, O.V. Abramov, V.A. Kashtanov, A.I. Medvedev, V.V. Lipaev, Y.N. Kofanov, V.V. N. Kofanov, as well as other Soviet and Russian scientists. However, the methods given in the existing scientific works rely only on the consideration of electrical, physical and other operational factors in assessing the " λ -characteristics". The methods are based on statistical ED data, but do not take into account the level of the necessary measures implementation according to the NTD in the terms of TD and the effectiveness of the QMS to confirm the full application of the regulated numerical value of the "production quality factor". This means that the approaches do not reflect a multifactorial (differential) assessment of the quality of design and manufacture of the RTD.

The following software is currently available to automate the assessment of particular reliability indicators: ASONIKA-K-SF and Relex (Reliability Prediction module). However, neither the integral nor the differential "production quality coefficient" is considered in the above-mentioned software. It is worth noting that, at the moment, there is no specialized software for assessing the "production quality coefficient" due to the fact that there is no method and methodology for its differential determination. The quality of additional ED tests, the extent to which

the results comply with the TD and the efficiency of the QMS at the design stage in assessing dependability are also not taken into account.

Author's personal contribution to the issue

The personal contribution of the author lies in his direct involvement in setting the objectives of the thesis research and solving them. The author personally proposed: a new method of dependability assessment, improving the accuracy of evaluation of single reliability indicators and considering multifactorial processes of design and production of space equipment RTD with regard to QMS, thus significantly reducing the relative error between the calculated and experimental data for EM1 class of receiving and transmitting devices; method of dependability assurance, improving the effectiveness of achieving the target dependability level by monitoring the dynamics of dependability indicators; new approach to the formation of a questionnaire for expert evaluation of the completeness of the normative and technical documentation required measures based on a strict structure (ontological approach represented by the composition scheme); an approach to the assessment of weighting coefficients of requirements of normative and technical documentation based on fuzzy logic and criteria for quality assessment of requirements, which improves the requirements management process in their formation. The author independently developed the architecture, software algorithm, user interface and implemented the final form of the software product to automate the processes of audits and analysis of design procedures, as well as organization management processes in assessing the dependability of space equipment RTD.

Within the dissertation research the author obtained 1 certificate of state registration of the software program № 2021616459 “ASONIKA-K-KP 1.0” and 1 certificate of state registration of the database № 2021620877 "Classification of GOST, OST requirements for radiotechnical devices on the stages of life cycle".

The author of the thesis has analyzed the obtained results and formulated conclusions on the dissertation work.

Description of research methodology

The methods used to solve the problems were dependability theory, structural analysis, ontological research, mathematical modelling, fuzzy logic and decision-making, set theory, probability and mathematical statistics, as well as methods of object-oriented programming.

Main results to be defended

1. A mathematical model of a differential "production quality factor" that improves the accuracy of calculated assessment of dependability indicators, in particular, EM1 reliability indicators class of receiving and transmitting devices and differs from the known one by taking into account factors describing the efficiency of required NTD measures and multifactorial processes at the LC stages.

2. Dependability assessment method for the space equipment RTD, which increases the probability of the rework influence on failures reduction for EM1 class of receiving and transmitting devices and differs from known ones by including step-by-step control of completeness of necessary measures at the design.

3. Methodology for ensuring the dependability of space equipment RTD, increasing the efficiency of achieving the target level of dependability of EM1 for the class of receiving and transmitting devices through the timely application of corrective actions at the stages of design and production and differing from existing ones, having the ability to predict the dynamics of the assessed dependability indicators

4. Software to automate the evaluation of the differential "production quality factor" of EM1 based on the results of the "design" and "production" LC stages with the possibility to evaluate the "production quality factor" at each stage of the life cycle and which differs from the known ones by enabling the analysis of audit results and by providing a visual representation of the achievable level of dependability.

Scientific novelty

1. A mathematical model of a differential "production quality factor" for space equipment RTD is proposed, which allows to consider the effectiveness of the implementation of necessary NTD measures at the "design" and "production" life cycle stages, including the effectiveness of the QMS operation.

2. A method for evaluating the dependability of space equipment RTD was developed to reduce the probability of rework in the final stages of the "design" and "production" life cycle by applying the ontological approach to the formation of a questionnaire for expert evaluation and subsequent analysis of audit results, as well as by applying quality criteria and fuzzy logic to assess the quality of requirements (measures) of technical specifications.

3. A methodology has been developed to ensure the dependability of space equipment RTD, which increases the level of project dependability through the timely application of corrective actions by means of strict localization of unfulfilled NTD measures (failures) at the design, production stages as well as at the formation of a feedback mechanism - preventive actions to ensure dependability.

4. Software has been developed to improve the performance of design procedures and dependability processes by providing a visual representation of the dependability level by analyzing the performance of measures during the "design" and "production" phases of the lifecycle.

General conclusions of the study

The following research tasks have been implemented as part of this dissertation research:

1. A review and analysis of the subject area of dependability assessment of the space equipment UAS and the impact of QMS on the LC stages during the lifetime have been carried out.

2. A mathematical model of the differential "production quality factor" was developed, considering multifactor processes and necessary NTD measures at the "design" and "production" LC stages of the space equipment RTD.

3. A method of evaluating the space equipment RTD dependability has been developed, which consists of a stage-by-stages LC stage control of the "design" and "production" of the EM1 and makes it possible to assess the completeness of the implementation of the necessary NTD measures at each stage.

4. A dependability assurance methodology has been developed that allows identifying the achievable level of dependability of the spacecraft RTD based on the results of design and production, and also makes it possible to identify "weak points" at the "design" and "production" stages to apply timely corrective actions required to ensure the required (target) level of RTD dependability.

5. Algorithm and software structure developed and implemented to automate the stages of space equipment RTD dependability assessment method.

6. The method of dependability assessment proposed in paragraph 3 was experimentally tested and the results of the study were implemented in the educational process of the Higher School of Economics, as well as in the design and production practices of Russian enterprises and companies.

The object of research "power and control module" has proven the feasibility of applying the method to reliably assess the dependability indicator of the RTD (EM1). This method calculates the actual level of dependability. It also demonstrates the efficiency of the developed methodology for ensuring the RTD (EM1) dependability at the life cycle stages according to the principles of quality management. In the first case, the actual situation with the achieved level of RTD (EM1) dependability is reflected, while in the second, the level of dependability is monitored in order to follow the dynamics of its change in the task of achieving it. This provides an early opportunity to identify and remedy any failures during the design stage, thus ensuring that the target level of dependability is achieved.

Also, knowing the effectiveness of the company's QMS, it is possible to pre-estimate the chances of achieving the target level of dependability.

Thus, the goal set has been achieved: An increase in the dependability of space equipment RTD of UAS is possible due to the provision of the calculated

assessment accuracy of the unit indicators of reliability at the early stages of design.

Achieving the target level of dependability and the quality of the space equipment RTD for the Russian space industry will lead to an increase in the rating and wealth of the Russian organizations. Also, the implementation of a "regulatory dependability budget" will reduce the risks of projects related to the provision of space communications services, which will have a positive impact on the country's profitability in this area.

The results of the dissertation research were included in the complex of measures to ensure dependability, carried out by enterprises. Certain provisions of the work are used in the educational process of higher educational institutions of the Russian Federation.

List of published articles reflecting the main scientific findings of the dissertation

Works published by the author in peer-reviewed scientific journals included in the international citation system Scopus:

1. **Korolev P.**, Sosnin A., Ivanov I. Development of the Dependability and Quality Assessment Method for the Design of Wireless Devices, in: 2021 International Seminar on Electron Devices Design and Production (SED). IEEE, 2021. P. 1-5. DOI: 10.1109 / SED51197.2021.9444504.
2. **Korolev P.**, Sedov K., Sosnin A. Dependability and Quality Satellite Telecommunication Equipment Improving at the Production Stage, in: 2020 Systems of signals generating and processing in the field of on board communications. IEEE, 2020. P. 1-5. DOI: 10.1109 / IEEECONF48371.2020.9078617.
3. **Korolev P.** Development of the Methodology for Assessing the "Production Quality Factor" for the Failure Rate Model of Artificial Earth Satellites Electronic Means, in: SYNCHROINFO 2020 Systems of Signal

Synchronization, Generating and Processing in Telecommunications. IEEE, 2020. P. 1-6. DOI: 10.1109 / SYNCHROINFO49631.2020.9166030.

4. Polesskiy S., **Korolev P.**, Ivanov I., Sedov K. Development of Methods for Identifying Factors Affecting the Electronic Tools Reliability in the Design, in: 2019 International Seminar on Electron Devices Design and Production (SED). IEEE, 2019. P. 1-5. DOI: 10.1109 / SED.2019.8798447.

Works published by the author in a peer-reviewed scientific journal included in the list of recommended journals of the National Research University Higher School of Economics:

5. **Korolev P. S.** Complex method of assessing the reliability indicators of radio technical devices of space equipment // Izvestiya vysshee uchebnykh obrazovatel'stva. Instrument engineering. 2021. T. 64. № 4. P. 316-328. DOI: 10.17586/0021-3454-2021-64-4-316-328.
6. **Korolev P. S.**, Zhadnov V. V. Estimation of "production quality factor" for failure rate model of radio technical devices of unmanned automatic spacecraft // Proceedings of Higher Educational Institutions. Instrument Engineering. 2020. T. 63. № 3. P. 264-277. DOI: 10.17586/0021-3454-2020-63-3-264-277.

Works published in other publications:

7. **Korolev P. S.** Method of "production quality factor" estimation of radio engineering devices of satellite communication systems // In the book: Proceedings of XV International branch scientific-technical conference "Information society technologies" Vol. 1. Publishing House Media Publisher, 2021. P. 111-113.
8. **Korolev P. S.**, Kunizhev I. R. Analysis of approaches to reliability assessment of unmanned spacecraft radio technical devices using quality management system // In: Proceedings of XIV International Scientific and Technical Conference "Information Society Technologies" Vol. 1. Moscow: Media Publisher Publishing House, 2020. P. 167-169.

9. **Korolev P. S.** Research of reasons of low dependability and quality of radio technical devices of space equipment at the design stage // In: Conference Proceedings. Interuniversity scientific and technical conference of students, graduate students and young specialists named after E.V. Armenskiy / Ed. by: E.A. Kruk, S.A. Aksenov, S.M. Avdoshin, U.V. Aristova, G.G. Bondarenko, L.S. Voskov, A.A. Elizarov, F.I. Ivanov, A.B. Los, N.S. Titkova. M.: MIEM NRU HSE, 2020. P. 140-141.
10. **Korolev P. S.** Development of software for estimation of "production quality factor" of radio technical devices for unmanned spacecraft // In: Proceedings of International Symposium RELIABILITY and QUALITY 2020, Vol. 2. Penza: Penza State University, 2020. p. 291-294.
11. **Korolev P. S.** Influence of hardware production quality factor on evaluation of radar equipment reliability indicators in RIAC-HDBK-217PLUS // In: Innovative, Information and Communication Technologies: Proceedings of XVI International Scientific and Practical Conference / Edited by: I.A. Ivanov. Association of Graduates and Employees of Zhukovsky Air Force Academy, 2019. p. 439-441.
12. **Korolev P. S.** Influence of quality management system in development of radio engineering devices within the concept of project learning in MIEM NRU HSE // In book: Interuniversity scientific-technical conference of students, post-graduates and young specialists named after E. E.V. Armenskiy / Under edition of E.A. Kruk, S.A. Aksenov, S.M. Avdoshin, U.V. Aristova, G.G. Bondarenko, L.S. Voskov, A.A. Elizarov, E.S. Klyshinskiy, A.B. Los, N.S. Titkova. M.: MIEM NIAU HIGHER EDUCATION, 2019. p. 147-148.
13. **Korolev P. S., Loseva M. V.** Research of influence of quality factor of apparatuses production on evaluation of dependability indicators of radio technical devices of communication systems // In the book: Proceedings of International Symposium on RELIABILITY AND QUALITY. T. 1. Penza: PSU Publishing House, 2019. p. 145-146.