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ANALYSIS OF THE INFLUENCE OF EXTERNAL FACTORS ON THE ACCURACY AND RELIABILITY OF MEASUREMENTS OF LOW-INTENSITY ELECTRIC FIELDS USING AN INFORMATION-MEASUREMENT SYSTEM

Abstract. This study focuses on developing and validating an information-measurement system for low-intensity electric fields. It examines the impact of external factors such as temperature, humidity, and mechanical stress on measurement accuracy and reliability. Advanced experiment planning using Sobol's LP_τ -sequences enabled precise data collection with an atomic force microscope sensor. Regression models were built and statistically validated to predict field characteristics under varying environmental conditions. The results demonstrate high measurement stability and metrological compatibility, highlighting the system's potential for industrial and educational applications.

Key words: low-intensity electric fields, measurement system, atomic force microscope, regression modeling, external factors influence, Sobol's LP_τ -sequences, measurement accuracy and reliability.

Introduction. During the study of accuracy and reliability in measuring low-intensity electric fields amid external disturbances, a key challenge is the predictive monitoring of the spatiotemporal state of a microelectronic device's quasi-static electric field. This involves extrapolating past patterns of field characteristic changes to forecast future values. A highly effective method for this task is developing a regression model that quantitatively captures how input variables affect measurement outcomes. Particular emphasis must be placed on experiment design and the careful selection of test points within a multidimensional space, as the model's quality and reliability heavily rely on the input data structure.

The primary **aim** of the work is to develop and analyze an information-measurement system for accurately and reliably studying static and quasi-static low-intensity electric fields, particularly by investigating the influence of external factors (such as temperature, humidity, and electromechanical effects) on the measurement results. This involves creating regression models using advanced experiment planning methods (like Sobol's LP_τ -sequences) to quantitatively describe these influences, ensuring high accuracy and repeatability of measurements conducted with an atomic force microscope equipped with a proprietary sensor. The work also includes statistical validation of these models, assessment of measurement stability, robustness under varying environmental conditions, and demonstration of practical applications in industrial and educational settings.

Methods and Materials. In the study of the accuracy and reliability of measuring low-intensity electric fields, particularly under the influence of external factors influence, a critical task is the predictive monitoring of the spatial-temporal state of the quasi-static electric field of a microelectronic device. This task involves extrapolating past patterns of change in the field's characteristics to predict future values. A highly effective method to address this is the construction of a regression model that quantitatively captures the effect of input variables on measurement outcomes. Careful consideration must be given to methods of designing experiments and the selection of test points in a multidimensional environment, as the robustness and accuracy of the model heavily depend on the input data structure. This approach ensures reliable forecasting of field behavior and improves understanding of measurement influences.

This section presents research devoted to analyzing the influence of external factors on the accuracy and reliability of measurements of low-intensity electric fields using a developed information and measurement system. Given the high sensitivity of electric fields to environmental

conditions such as temperature, humidity, and mechanical stress, experiments were conducted to assess their impact on measurement characteristics.

A methodology for constructing and analyzing regression models to describe the influence of external factors (temperature, humidity, electromechanical impact) on the force (electric field strength) and energy (electric potential) characteristics of low-intensity electric fields is presented. Sobol's LP_τ-sequences were used to form the experiment plan, ensuring uniform filling of multidimensional space and high sample informativeness. Measurements were performed using an NT-206 atomic force microscope equipped with a proprietary sensor under controlled environmental conditions. Statistical analysis was performed in the Statistica Data Miner environment using various types of models, including decision trees, support vector methods, artificial neural networks, MARS, and classical multiple regression. The best models for predicting responses Y_1 and Y_2 were selected, their adequacy was confirmed using Fisher's criteria, t-criteria, and residual analysis, and the models were deployed to evaluate new data. The results of the experiments showed that an increase in temperature from 10°C to 40°C (Table 1) causes an increase in electric field tension by 22% for the measured values and by 20.4% for the reference values. At the same time, the relative measurement error did not exceed 1.4%. For relative humidity, it was found that an increase in this parameter to 70% causes a decrease in electric fields intensity by 39.89%, which is explained by an increase in the electrical conductivity of the surface of the studied samples. In addition, mechanical impact within the range of up to 1500 Pa showed that at pressures above 1106 Pa, there is a significant decrease in the charge on the surface of the sample due to a change in its mechanical properties.

To assess the accuracy of the measurements, the root mean square error was used, the value of which varied from 0.018 V/m to 0.050 V/m, indicating high stability of the results. The probability of failure-free operation of the information-measurement system was at least 0.945 under optimal research conditions. The reproducibility of the results was assessed by the standard deviation, which was 0.056 V/m, and the reproducibility limit did not exceed 0.155 V/m, confirming the high metrological compatibility of the obtained data.

Table 1. Change in electric field strength with temperature [1]

T, (°C)	Field intensity, (V/m)		Relative error, (%)
	Average reference value	Average measured value	
10	9.55	9.65	1.04
15	9.88	10.01	1.32
20	10.20	10.36	1.56
25	10.53	10.72	1.80
30	10.85	11.06	1.94
35	11.18	11.43	2.24
40	11.50	11.78	2.44

Conclusions. A software-implemented mathematical model and corresponding algorithm were developed to accurately and promptly determine the distribution of force and energy characteristics of ultra-low intensity electric fields. This model takes into account their temporal dynamics, spatial parameters, and the effects of external influences. An information-measurement system utilizing an atomic force microscope was created to investigate low-intensity electric fields generated in microelectronic devices during operation, enhancing the precision and consistency of measuring these characteristics.

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