UDC 621.317.31; 519.6.

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AUTOMATED SYSTEM OF SCANNING THE SURFACE POTENTIAL

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АВТОМАТИЗОВАНА СИСТЕМА СКАНУВАННЯ ПОВЕРХНЕВОГО ПОТЕНЦІАЛУ

Purpose. Development of an automated system of scanning the surface potential by criteria of efficiency, universality, adaptability, accuracy and speed.

Methodology. The structural and parametric optimization of the system was performed by using multivariate analysis at the macro-level by the tools of behavioral simulation in Micro-Cap 11 program, according to the principles of research of multi-domain systems in Automatic Control Theory.

Findings. Due to three stepper motors, controlled by the microcontrollers, this system allows one to fully automate the surface scanning process, improve the accuracy and speed measuring a contact potential difference on the basis of Kelvin method. A number of new models for virtual experiment at macro-level in ECAD applications have been developed. A prototype system has been designed and experiments with different materials, coatings and films have been conducted.

Originality. New models of elements for automatic control systems which are relevant to the criteria of adequacy and efficiency and are supplemental to ECAD software for analyzing mechatronic systems have been developed.

Practical value. Compared with prototypes, these systems have distinctive features such as low cost, full automation of scan, variation of scale and the number of steps, as well as automatic compensation of potential difference. Due to the full automation, the proposed system increases the possibility to analyze the structural, electrical and physical state of surface of different materials, while its low cost and adaptability expands its possible application for the educational process. Models of Control System elements have been installed in the ECAD library and are available now for using in analysis of mechatronic systems.

Keywords: *the electrical and physical properties of materials, surface potential, Kelvin method, dynamic capacitor, scanning, mechatronic system, automated measurements, modeling at the macro level*

Introduction. A promising way to control the properties of the surface layer of tribological products, including the study of the quality tool material surfaces, is to scan its surface potential (SP), i.e. registration of changes in the electron work function (EWF) on the surface of the material. EWF is a fundamental characteristic of a solid state that determines its emission, contact and adsorption properties, and depends on thermo-dynamical parameters, chemical and phase composition of the solid state and its surface, including the anisotropy, sensitivity to the composition and unevenness of film thickness across the surface, the presence of deformities and defects, etc. [1].

On the basis of SP measurements a lot of methods of diagnostics of electrical and physical parameters of materials have been developed. EWF is usually determined through the contact potential difference (CPD), which is the difference between EWF of a sample and EWF of test material.

Unsolved aspects of the problem. Currently, there are several types of devices for the measurement of the CPD on the basis of Kelvin method, including scanning probe microscope [2], which, for all its virtues, has a small scanning field (around 1 millimeter) and a high cost (hundreds of thousands of Euros). The required time to obtain images varies from several minutes to several hours, which limits the application field of such microscopes.

Other known devices for SP-measurement do not allow automatic scanning in all spatial directions and are generally not adapted for measuring in other conditions (e.g., in vacuum). Thus, the development of an inexpensive system with variable sizes of a field and step of scanning to assess the quality of products of a tribotechnical purpose is an actual problem.

Analysis of the recent research and publications. Analysis of low-cost devices for SP measuring, during the preparation of the patent for utility model [3], has shown that because of incomplete automation of transferring probe to the optimal distance from surface, the time of measurement and risk of damaging thin films increase significantly. In the device [4], this risk is reduced by the restrictive mechanism; however, measurements are made in the semi-automatic mode, in the single point of sample.

The apparatus [5] monitors the parameters changing by detecting signals from various sensors (EWF, friction torque, wear, body temperature and so forth.) in the selected band of the rotating sample.

All the analyzed devices have in common the lack of the possibility for automatic changing of the probe position (movement by all spatial coordinates – scan); and due to the partial automation of the process and considerable size of equipment, all those devices cannot be adapted for measurements in vacuum.

Objectives of the article. The aim of this study is to develop a SP measuring system that is able to provide automatic movement of the probe relative to the sample surface (scanning). Among the desired quality criteria are: efficiency, universal application, automation, reducing time of the measurement while maintaining the accuracy; exclusion of probability of damaging the probe and sample surface in the process of measuring; variation of sizes of a step and sample.

Presentation of the main research. Taking into account the above-defined quality criteria, a conceptual model of the CPD measuring device was developed. By using the stepper motor, this device performs an automatic approach (*Z*-direction) of the vibrating probe to the sample surface up to an optimum distance, compensates the resulting potential difference, determines the dead-band (i.e., the range of compensation voltage when the oscillating signal from the capacitor approaches zero). The stepper motor is controlled by an automatic control system (ACS).

Schematic representation of the moving mechanism of the probe in *Z*-direction is presented in Fig. 1.

Depending on the value of the dead-band range, ACS determines the continuing movement of the probe closer to the surface, or moves to a different sample area for the measurement. The measured values of compensation voltages are stored in the computer, the probe rises up to a safe distance from the sample, and position of the table with sample in the *X*- and *Y*-direction is changed for further measurements.

The probe (the upper part of the dynamic capacitor) has a circular shape with a diameter of 1 mm, made of gold 975, the optimal distance for such a probe from the surface ("zero point") is 100 mm [6], which is determined by the range of compensation voltage (the algorithm is presented below).

The radiating element of a woofer speaker (diffuser) was chosen as a sine-wave oscillator. It operates as a piston, and rigid membrane oscillates relating to the permanent magnet with frequency of the generated sound (in the investigated system – 1 kHz) and amplitude of about 50 microns. The system provides the probe's movement with the control of the minimum distance from the surface (10 microns) and automatic movement of the sample to the *X*-, *Y*-, *Z*-coordinates by using the three stepper motors which are controlled by the micro-controller under the given algorithm, with the possibility of interruption from the operator. Thus, this device can be assigned to class of mechatronic automatic control systems (ACS).

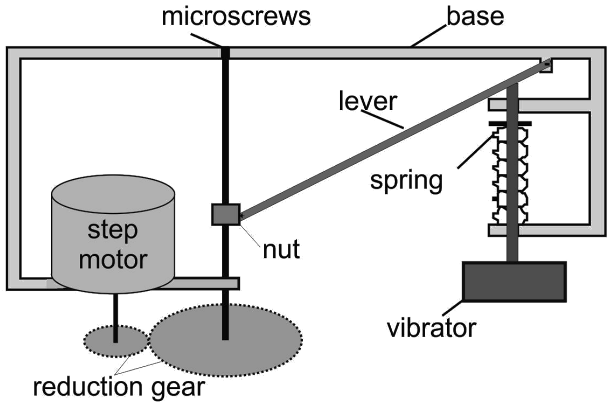

Fig. 1. Schematic representation of the moving mechanism of the probe, Z-direction

Macro-modeling of the mechatronic systems. This mechatronic system includes a diffuser, set of mechanical transducers (gears, levers, spring, reduction gears), stepper motors (SM), electronics subsystems (analog and digital), micro-controller and sensors. Thus, this system is the multi-domain and for its investigation at the macro-level, it is necessary to utilize specific mathematical tools and software [7].

In this case, a demo version of ECAD software Micro-Cap 11 [8] was used, which due to a set of behavioral modeling tools will allow us to abstract from the physical properties of a particular domain during the construction of multi-domain model of the generalized ACS [7]. For modeling algorithm of ECAD, ACS model is a quasi-causal: despite the pre-formed causal relationships (causality), the resulting model is a-causal, because it is the system of nonlinear differential equations, which is obtained by program automatically in an implicit form, according to the user-defined substitution scheme [7, 8].

Since the task of simulation is to assess working capacity and reliability of the system as a whole, instead of clarifying the features of the work of its separate elements, simplified macromodels for ACS blocks can be used. Such macromodels have been developed in this study.

Dynamic macromodel of CDYN capacitor, which changes its charge due to the distance changes between the probe and the sample surface by the known formula [6], and a scheme for the analysis of its characteristics are shown in Fig. 2.

Source V_{test} allows emulating the measured CPD. DC current source (VCC) generates a constant bias

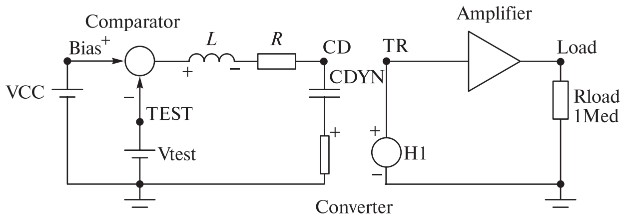

Fig. 2. Schematic representation for Dynamic capacitor analysis

(V_{bias}), its variation will determine CPD under the condition of the capacitor's current being equal to zero, which is determined in "Comparator" block. The Comparator is implemented on an algebraic adder, which takes into account the sign of summands. An active input impedance of the amplifier (Load) is represented as resistor R_{load} = 1 MOhm.

"Converter" block is based on the voltage-controlled current source H1, which converts the current into a voltage for further amplification in "Amplifier" block and for measurement, also provides galvanic isolation (to improve the accuracy of capacitor's current measurements), and gives the model attributes of causality, which is typical for ACS models in the automatic control theory [7].

System simulation in Micro-Cap 11. The results of simulating the dynamic capacitor in Transient Analysis (timing diagrams), namely, changing of capacitance, charge and current under the bias voltage varying (V_{bias}) are shown in Fig. 3. Diagrams are generated by the Micro-Cap 11 program [8].

The adequacy of the model is confirmed by the fact that the current and charge of the capacitor become zero, when voltage V_{bias} is equal to voltage V_{test} (CPD). By exceeding CPD voltage, overcharging of capacitor occurs and the phase of current is inverted. The simultaneous reduction in distance between electrodes and an increase in the amplitude of the probe oscillations make it possible to increase sensitivity of the sensor. The influence of the parasitic properties of the connecting wires and other elements of the installation (modeled by R, L-elements) at a frequency of 1 kHz is negligible.

Vertical movement of the probe by means of a stepper motor (SM), which rotates through a certain angle, is proportional to the number of pulses received from the driver. For precise control of the distance of the probe from the surface of the sample, it is necessary to convert rotary motion into linear one through a system of gears and levers, with a reduction to a few microns. To achieve this goal, it is proposed to use a stepped system (Fig. 1): at first speed via the gear system is reduced; then through the screw gear, the rotational movement is converted into linear; and then through a system of levers and springs movement is transmitted to the probe holder. The controlled distance from the surface is 10 microns (minimum).

Complete equivalent circuit of the system model is shown in Fig. 4. It consists of such macromodels:

1. The block for modeling a bipolar stepper motor ("Stepper Motor") sets the conversion of the number of control pulses (from input node IN) to a rotation angle (to the output node Degree), implemented on the proportional-integrating block. Resonance in SM is not modeled due to the damping of oscillations in the transmission system.

2. Stepper Motor Driver modeled by composition of VINSM Pulse generator with the time delay and source NF, which can turn off SM, if optimum distance is achieved (this algorithm is given in the NF).

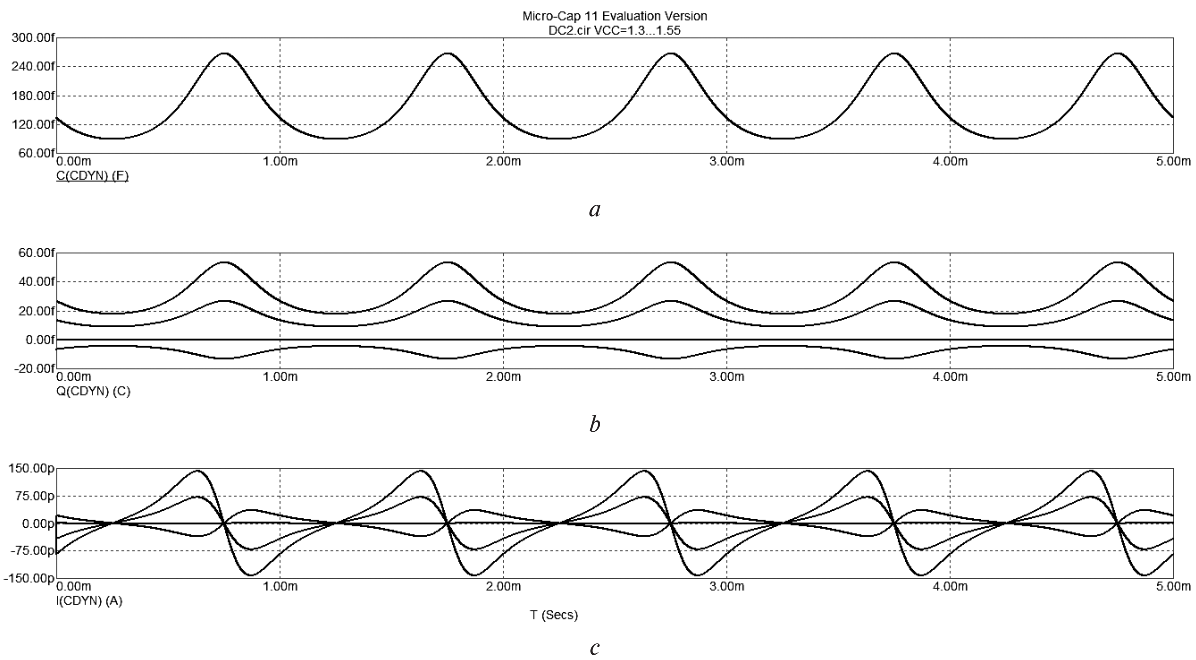

Fig. 3. The results of multivariate analysis of the dynamic capacitor (probe) in Micro-Cap 11 environment:
a – capacitance of dynamic capacitor C(CDYN), F; b – the charge on the plates of the capacitor Q(CDYN), Cl; c – the capacitor's current I(CDYN), A

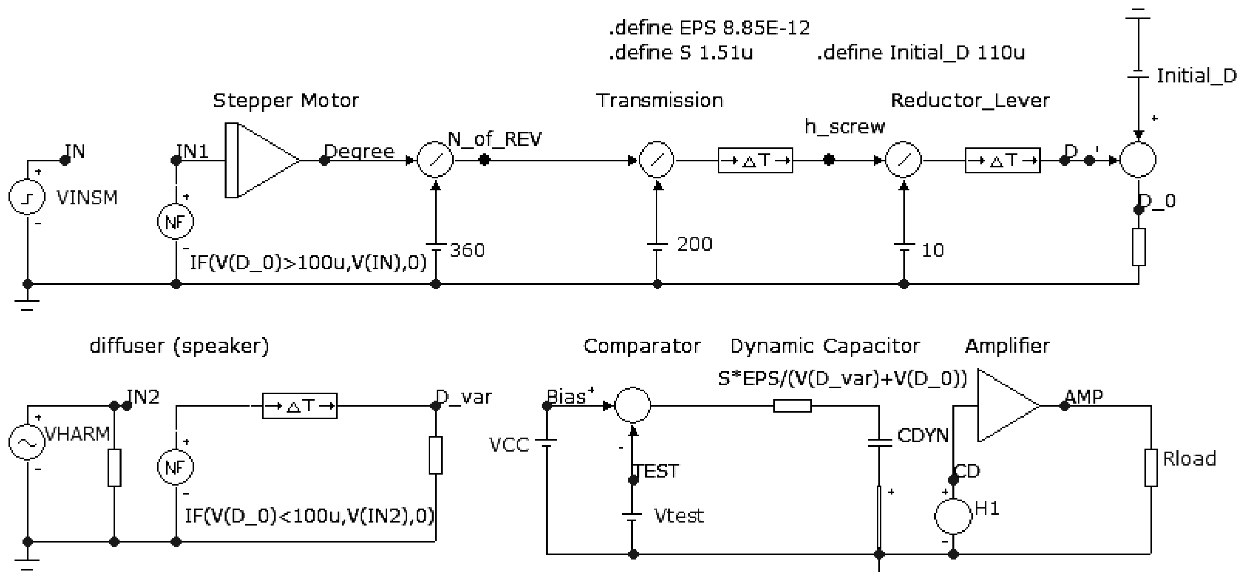

Fig. 4. Total macromodel of ACS, formed in Micro-Cap 11

3. The blocks, which define the number of revolutions (N_of_REV) and movement (h_screw) of the nut on the screw (M2 × 0.5) are modeled by voltage dividers.

4. Gear ratios for transmissions and reducers for "Transmission" and "Reductor_Lever" subsystems and the initial distance from the surface (Initial_D) are defined in the DC sources (batteries).

5. The block for calculating distance from the surface (D_0) is modeled by "Sub" macros, wherein D_0 is calculated as the difference between the initial value (Initial_D) and the *Z*-direction current displacement (D).

6. "Dynamic capacitor" CDYN Block (Fig. 2).

7. "Diffuser" Block (diffuser/speaker) is specified by the generator of VHARM sinusoidal oscillations with time delay and its "Turn-off" system (the condition defined in IF operator in the NF source), when the probe approached the optimum distance.

8. The path of the analog gain is simulated by the macro Amp; the comparator is implemented on the macro "Algebraic adder" Sub; load is modeled as resistor (Rload = 1 MOhm).

The model's causation is provided by galvanic isolation due to dependent sources which are present in all macros. Elements that set the time delay ΔT, increase the accuracy of the reproduction of dynamic characteristics, and reduce the risk of emergence of algorithmic failures during simulation.

Fig. 5 illustrates the results of the system simulation with the stepper motor. The results of the simulation of the full scan system model are shown in Fig. 6. All waveforms are generated in Micro-Cap 11 program, in which the function and argument are signed on the left, below the graphs.

Fig. 5 (upper graph) shows how each driver pulse (amplitude of 5 V, 5 ms period) rotates the SM rotor by 1.8° (lower graph); thus, SM completes a full rotation per 200 pulses; SM inertness is also taken into account, which indicates adequacy of the model. All graphics are waveforms (timing characteristics).

The upper graph of Fig. 6 shows the simulation results of changes in the distance between the probe electrodes D_0 + D_VAR from $150 \cdot 10^{-6}$ to $50 \cdot 10^{-6}$ (m),

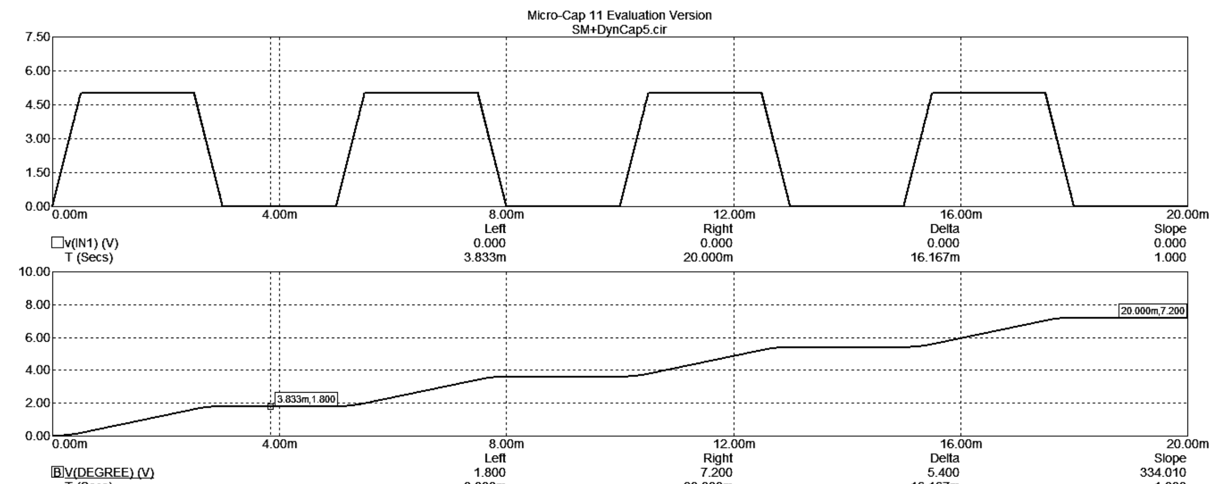

Fig. 5. Simulation of SM: pulses from the driver (upper graph) and rotor reaction (below graph)

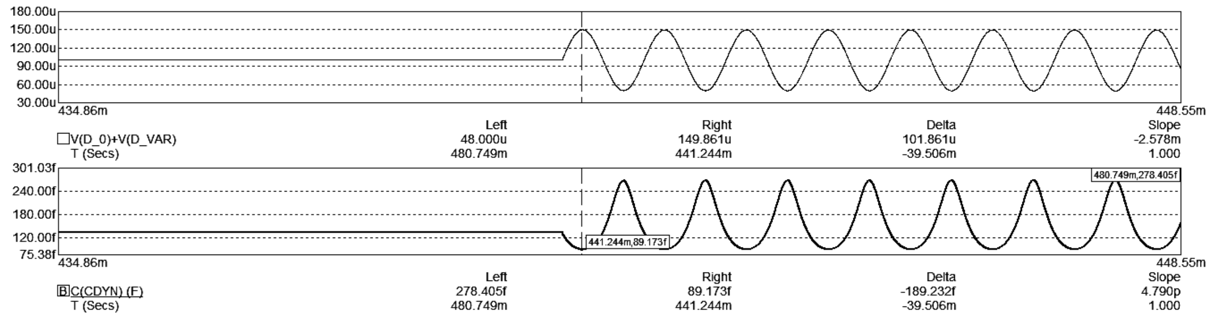

Fig. 6. Simulation of SP-scanning system: distance from the probe to the surface (upper graph); variation of the probe capacitance (lower graph)

causing the capacitance change from $89 \cdot 10^{-15}$ to $278 \times \times 10^{-15}$ (F), as represented in the lower graph, respectively.

For clarity of information presentation, only a small time period of the system work is shown, after release of the probe at the optimal distance from the sample (from about 435 to 448 ms), without variation of the bias voltage and without the action of automation. Changing the oscillation amplitude, the various values of capacitance, the probe output voltage and sensitivity were obtained. The resulting value of the modulation factor is 0.5 [6]. Our research has also shown that the system is stable.

Full-scale experiments. After the model experiment, in which the parameters of the system were optimized and refined on the basis of physical features of the real hardware, a prototype was designed [3]; and CPD of materials with different coatings were studied.

The new technical solution, used in the design of the installation, is that it controls the probe-sample gap according to the range of compensation voltage V_{bias}; based on its value, the ACS makes a decision about the necessity of gap changing. When the measurement is considered complete, the block of the measurement and control stores the value of V_{bias} range, and then picks up the probe over the surface and moves the sample at one given step in *X*-, *Y*-directions, and the measurement process is repeated. Upon completion of the scan, data of a predetermined surface area is transferred to a PC for further processing.

Using this system SP was measured for various materials at various conditions. Since the analysis of the results of measurements is the subject of a separate study, the reported result for this study is the CPD of the conducting plate (Fig. 7), on which the non-uniform thickness film was formed (with the greatest thickness in the center). The dimensions of the plate are plotted on the X and Y axes in mm and on the Z-axis – measured CPD in meV. Grayscale shows the CPD change from the minimum 100 meV (black) to the maximum – 220 meV (white color). It is obvious that the highest value of CPD has a surface with a maximum thickness of the coating.

Conclusions. The designed tool is sufficiently sensitive and can be recommended for the non-destructive testing of structural and physical-chemical state of the surface. The features of the developed system are the realization of 3D-movement with automatic control of the gap and step produced while scanning samples of varying sizes and thickness. Using a non-contact method and automatic compensation of the potential difference increases measurement accuracy (absolute error in determining the SP is not more than ± 5mV).

The plate size for scanning may vary; for the existing vacuum chamber it was 35 × 60 mm. Minimum scan step size is caused by the probe size, it is defined by the software in the range of 1 to 5 mm. The operation speed of the system was conditioned by the degree of uneven thickness of the sample, because the process of precision movement of the probe to the optimal distance from the surface is the most time-consuming, and is dependent on the number of points to measure. The cost of components for this system (2015 pricing) is about 20 €.

The low cost and adaptability of the system allows recommending it for use during the design cycle of high-performance products for tribotechnical purposes [1], in determining regularities of wear process in conjugate solid bodies, in studying the properties of nano-structured coatings, and for other tasks, as well as in the educational process.

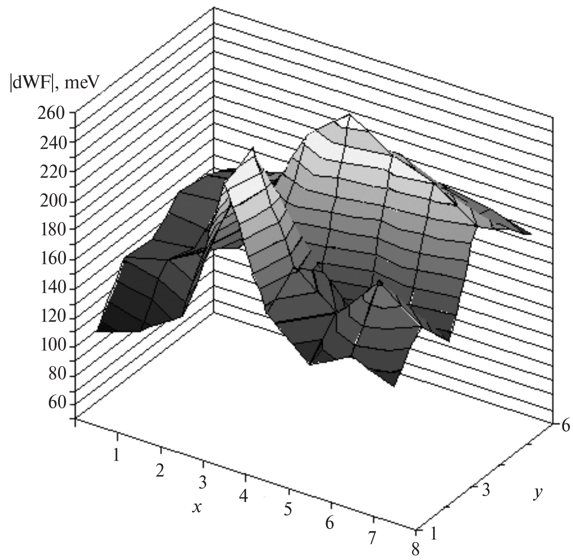

Fig. 7. Distribution of CPD on a sample surface

References/Список літератури

1. Panteleev, K.V., Svistun, A.I. and Zharin, A.L., 2014. Methods of measurement of the electron work function to monitor the status of surfaces under friction. *Pribory i metody izmerenii,* No. 2, pp. 107–112.

Пантелеев К.В. Методы измерений работы выхода электрона для контроля состояния поверхностей в процессе трения / К.В. Пантелеев, А.И. Свистун, А.Л. Жарин; Приборы и методы измерений – 2014. – № 2. – С. 107–112.

2. Laurent, Nony. 2013. *Principles of Kelvin Probe Force Microscopy and applications.* [online] Marseille, France. Available at: https://cel.archives-ouvertes.fr/cel-00917935/document.

3. Zhavzharov, I.L., Nagorna, N.M. and Smyrnova, N.A., Zaporizhzhya National Technical University, 2006. *The device for automatic measurement of potential difference by contactless method.* Ukraine. Pat. 104591.

Патент. 104591 Україна, МПК G01R 29/12 (2006.01), G01N 27/87 (2006.01). Пристрій для автоматизованого вимірювання контактної різниці потенціалів безконтактним методом / Жавжаров Є.Л., Нагорна Н.М., Смирнова Н.А.; власник Запорізький національний технічний університет. — № u201507171; дата заявки 17.07.2015; дата публік. 10.02.2016, Бюл. № 3, 2016.

4. Kompaniiets, I.V., Shkilko, A.M. and Borysov, V.V. Ukrainian Engineering and Pedagogical Academy, 2009. *Device for measuring the surface potential.* Ukraine. Pat. 39395.

Патент. 39395 Україна, МПК G01R 29/12. Пристрій для вимірювання поверхневого потенціалу / Компанієць І.В., Шкілько А.М., Борисов В.В.; власник Українська інженерно-педагогічна академія. — № u200811428; дата заявки 22.09.2009; дата публік. 25.02.2009, Бюл. № 4.

5. Zharin, A., 2010. Contact Potential Difference Techniques as Probing Tools in Tribology and Surface Mapping. In: B.Bhushan, ed. 2010. *Scanning Probe Microscopy in Nanoscience and Nanotechnology*. Springer Berlin Heidelberg. DOI: 10.1007/978-3-642-03535-7_19

6. Kompaniiets, I.V. and Shkilko, A.M., 2010. Metrological maintenance of the meter contact potential difference. *Visnyk Natsionalnoho Tekhnichnoho Universytetu* "*KhPI*", Special issue: "New solutions in modern technologies", No. 57, pp. 150–153.

Компанеец И.В. Метрологическое обеспечение измерителя контактной разности потенциалов / И.В. Компанеец, А.М. Шкилько; Вестник Нац. техн. ун-та "ХПИ": сб. науч. трудов, темат. вип.: "Новые решения в современных технологиях". – 2010. – № 57, – С. 150–153.

7. Vasylenko, O.V., 2015. Analysis of programs for mechatronic systems modeling. *Radioelektronika, informatika, upravlenie*. No. 2, pp. 16–31.

Василенко О.В. Аналіз програм для моделювання мехатронних систем / О.В. Василенко; Радиоэлектроника, информатика, управление. – 2015. – № 2. – С. 16–31.

8. Micro-Cap 11 Electronic Circuit Analysis Program. User's Guide. © Spectrum Software. 1982–2014. [online] Available at: http://www.spectrum-soft.com/down/ug11.pdf

Мета. Розробка автоматизованої системи сканування поверхневого потенціалу, що відповідає критеріям економічності, адаптивності, точності та швидкодії.

Методика. Структурна й параметрична оптимізація системи здійснювалася за допомогою багатоваріантного аналізу на макрорівні засобами поведінкового моделювання у програмі Micro-Cap у відповідності до принципів дослідження мультидоменних систем у теорії автоматичного управління.

Результати. Спроектовано мехатронну систему, що завдяки використанню трьох крокових двигунів, керованих мікроконтролером, дозволяє повністю автоматизувати процес сканування поверхневого потенціалу, підвищити точність і швидкодію вимірювання контактної різниці потенціалів на основі методу Кельвіна. Розроблено ряд нових моделей для проведення модельного експерименту на макрорівні в середовищі ECAD програм. Спроектовано дослідний зразок системи й проведено натурні експерименти з різними матеріалами та покриттями.

Наукова новизна. Розроблені нові моделі елементів систем автоматичного управління, що відповідають критеріям адекватності та економічності, які доповнюють математичне забезпечення й розширюють можливості ECAD для аналізу мехатронних систем.

Практична значимість. У порівнянні з прототипами розроблена система має такі відмітні ознаки, як мала собівартість при повній автоматизації сканування, варіація розміру та кількості кроків, автоматична компенсація різниці потенціалів. Запропонована система, зважаючи на повну автоматизацію, розширює можливості аналізу структурного та фізико-хімічного стану поверхонь, а її низька собівартість і адаптивність розширює сферу її можливого застосування аж до навчального процесу. Розроблені моделі елементів моделі системи інстальовані в бібліотеку ECAD і доступні для аналізу мехатронних систем.

Ключові слова: *електрофізичні властивості матеріалів, поверхневий потенціал, метод Кельвіна, динамічний конденсатор, сканування, мехатронна система, автоматизовані вимірювання, моделювання на макрорівні*

Цель. Разработка автоматизированной системы сканирования поверхностного потенциала, соответствующего критериям экономичности, адаптивности, точности и быстродействия.

Методика. Структурная и параметрическая оптимизация системы осуществлялась с помощью многовариантного анализа на макроуровне средствами поведенческого моделирования в программе Micro-Cap в соответствии с принципами исследования мультидоменных систем в теории автоматического управления.

Результаты. Спроектирована мехатронная система, благодаря использованию трех шаговых двигателей, управляемых микроконтроллером, позволяет полностью автоматизировать процесс сканирования поверхностного потенциала, повысить точность и быстродействие измерения контактной разности потенциалов на основе метода Кельвина. Разработан ряд новых моделей для проведения модельного эксперимента на макроуровне в среде ECAD программ. Спроектирован опытный образец системы и проведены натурные эксперименты с разными материалами и покрытиями.

Научная новизна. Разработаны новые модели элементов систем автоматического управления, отвечающие критериям адекватности и экономичности, которые дополняют математическое обеспечение и расширяют возможности ECAD для анализа мехатронных систем.

Практическая значимость. По сравнению с прототипами разработанная система имеет такие отличительные признаки, как малая себестоимость при полной автоматизации сканирования, вариация размеров и количества шагов, автоматическая компенсация разности потенциалов. Предложенная система, учитывая полную автоматизацию, расширяет возможности анализа структурного и физико-химического состояния поверхности, а ее низкая себестоимость и адаптивность расширяет сферу ее возможного применения для учебного процесса. Разработанные модели элементов модели системы установлены в библиотеку ECAD и доступны для анализа мехатронных систем.

Ключевые слова: *электрофизические свойства материалов, поверхностный потенциал, метод Кельвина, динамический конденсатор, сканирование, мехатронная система, автоматизированные измерения, моделирование на макроуровне*

Рекомендовано до публікації докт. техн. наук Т. В. Критською. Дата надходження рукопису 22.02.16.

UDC 621.9.06

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DEFINITION OF VIBRO DISPLACEMENTS OF DRIVE SYSTEMS WITH LASER TRIANGULATION METERS AND SETTING THEIR INTEGRAL CHARACTERISTICS VIA HYPER-SPECTRAL ANALYSIS METHODS

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ВИЗНАЧЕННЯ ВІБРОПЕРЕМІЩЕНЬ СИСТЕМ ПРИВОДІВ ЗА ДОПОМОГОЮ ЛАЗЕРНИХ ТРІАНГУЛЯЦІЙНИХ ВИМІРЮВАЧІВ ТА ВСТАНОВЛЕННЯ ЇХ ІНТЕГРАЛЬНИХ ХАРАКТЕРИСТИК МЕТОДАМИ ГІПЕРСПЕКТРАЛЬНОГО АНАЛІЗУ

Purpose. Experimental measurements of vibro movement of the spatial drive system using laser triangulation sensors and definition of integrated dynamic characteristics of a drive using hyperspectral analysis methods.

Methodology. Experimental research methods using high-precision laser triangulation sensors of vibro movement and application of hyperspectral analysis methods based on multiple (two-dimensional) Fourier series for processing the measurement results of vibro movement of the table of spatial drive system .

Findings. The technique of precision dimensions (0.2 mm) of vibro movement of the table of the spatial drive system was developed. Projections of displacement of the table and the trajectory of its movement are determined. We established that the set of trajectories is described by the fuzzy sets and proposed analytical dependencies that describe the membership functions of the fuzzy sets. Application of hyperspectral analysis methods for determining the integrated dynamic characteristics of the spatial drive system was substantiated.

Originality. High-precision measurements of vibro movement of the spatial drive systems were obtained for the first time. In this study it was established that on exposure to the dynamic load we receive the displacement projection of a table with high-frequency oscillation parameters, which are fuzzy. This causes ripple movement of the table and uncertainties of the trajectories, which are located within the elliptical stripe. The location of the table within the band