Principles of discrete-event modeling of physical processes during technical surfaces contact interaction

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Abstract. The article discusses the advantages and disadvantages of computer modeling used in physical experiments field on rough surfaces contact interaction. Methods for constructing the software model are given. The description of a single irregularity in the form of revolution ellipsoid segment is presented and an algorithm for rough surface three-dimensional modeling based on it is proposed. Some assumptions made for generating surface topography do not significantly affect the simulation validity. Taking into account the individual parameters of each irregularity and the algorithm for their distribution make it possible to create inhomogeneous rough surfaces that are close to real ones relative to the physical experiments being carried out. The general principles of the software architecture and the data storage model of discrete-event modeling system of rough surface contact interaction are described. The developed software can be used for modeling the rough surfaces contact interaction, for researching of tribo-interface units’ parameters, predicting the characteristics of frictional interaction and tribotechnical tests computer simulation.

1. Introduction
Due to information technologies development, computer modeling systems are often used in solving applied engineering problems. They are built into design calculations algorithms, modernize their methods, offering more efficient solutions. Modern computers, which make it possible to operate with large amounts of computational data, make it possible to use them to simulate physical experiments. Systems of this kind do not supplant any of the research components, but are integrated into the overall process, optimizing the implementation of task solving each stage. The main advantages of this approach are:

- human factor influence minimization in the calculation part of the problem being solved - all internal calculations are included in the program algorithms and do not require external intervention;
- modeling help system - integration into prompts system interface, assistant implementation for step-by-step creation of modeling execution request and controlling module for input parameters entry, provide operator errors reduction when setting the task in a software environment;
• conducting virtual tests in the accelerated mode - only machine time is spent on calculating the result of the modeled process or influence result variation of inherent factors on the object under study;
• efficient sampling and data collection, with different variance of their presentation - the output of the results in the form laid down in the construction of the system: tables, graphs, three-dimensional objects, etc.
• conducted experiments visualization - the ability to visually show modeled process result or its state of simulation at a selected time.

The disadvantage of computer modeling lies in the variability of the tasks that are assigned to the program. Most often, software products developed for simulating a physical experiment have a narrow scope. When changing the formulation of the problem being solved: a radical change in the input parameters affecting the simulation object or a change in the object itself that was not initially included in the algorithm, a software revision of the simulation toolkit is required, or the creation of a software product with an updated structure. It is possible to expand the possible range of tasks by putting in the model the maximum number of experimental options, but this leads to an exponential increase in algorithm complexity, which, in turn, leads to increase in labor costs and increase in algorithmic errors probability.

2. Statement of the problem
The purpose of this article is to describe the software architecture and data storage model for carrying out numerical experiments using discrete-event computer modeling of contact processes and rough surfaces frictional interaction.

There are several formed approaches in this direction [1, 2], however, they are based on surface relief artificial creation and are based on random field theory. Due to the theory of random field, it is possible to obtain surface spectral characteristics. If we apply solutions for the periodic problem of the elasticity theory with sinusoidal stamp, then it can be used to determine the contact characteristics of technical surfaces [2]. The use of fractal geometry methods to describe topography and contact interaction of surfaces is used for research on a wide range of scales. However, this is unacceptable for surfaces contact interaction simulating [2], since there is no reliable description of actual contact spots distribution in the investigated area. By applying these algorithms often, it is possible to obtain a discrepancy between the constructed computer model and surface real microgeometry. When compared with real technical surfaces subjected to various processing technologies [3], such assumptions give a significant experimental error.

3. Model description
Computer model description can be divided into primary and secondary components. The primary one is rough surfaces microtopography generation and contact interaction characteristics calculation. Secondary - contains specialized modules that can be connected depending on the requirements of the task: frictional interaction, electrical resistance, forced test modes, thermal resistance, etc. This principle allows you to supplement the program with new capabilities and modify existing secondary systems.

Creation of a three-dimensional computer model with the ability to mathematically describe the change in surface morphology requires making a number of assumptions about the generated relief. The choice of surface topography model is one of the key issues in contact interaction simulations [4]. In this work [5], they are modeled by spherical segments. To describe their deformation, exact and approximate solutions of contact problems were used. The modeling of microgeometry took into account the distribution of irregularities radii and their height, but this was based on profilographs analysis of technical surfaces and did not adequately describe their topography. The problems of modeling microtopography in contact interaction can be limited to considering a part of a rough surface above the level of the median plane [6]. This will reduce resources consumption and will not affect the scope of the software tool.
More general case of a single irregularity model is revolution ellipsoid segment [7], which, in contrast to a spherical segment, allows one to take into account rough surfaces anisotropy arising during machining. In figure 1 shaded area - revolution ellipsoid segment above the median plane.

![Figure 1. Generated single asperity view.](image)

Initially, for each irregularity within the established boundaries, the following parameters are generated: height above the median plane $h$, longitudinal and transverse radii $R$, $R'$. This is the primary data obtained from the study of technical surfaces microtopography. For real surface correct generation, the operator can set the interval in which irregularities parameters will change. The beta distribution [5] (equation (1)) was chosen as a random distribution law. This allows maximum flexibility in customizing the generated relief.

$$f(z) = \frac{\Gamma(v+w)}{\Gamma(v)\Gamma(w)} z^{v-1}(1-z)^{w-1}$$

Depending on parameters values, the probability density function can be unimodal (with a maximum), $U$-shaped (with a minimum), uniform, monotonically increasing and decreasing. Using the beta distribution, it is possible to model both Gaussian surfaces and surfaces with a deterministic component.

Segment section length and width along the median plane $a$ and $b$, respectively, are calculated and saved.

The coordinates of the bases are distributed over the surface of the median plane according to the selected distribution law, taking into account the longitudinal $S$ and transverse $S'$ steps between irregularities. The distribution algorithm is software separate module and, if necessary, can be modified depending on the formulation of numerical experiment problem. Initially, irregularities equiprobable distribution over the surface without intersections was taken. It meets a wide range of applications and is convenient for testing.

Modeling of contact interaction is carried out by iterative approach of the surface to the half-space. In this case, the generated surface has the reduced roughness parameters corresponding to the case of contact between two rough surfaces [8]. Asperity changed parameters that have entered into contact interaction are calculated individually at each step of penetration, taking into account their elastic or elastoplastic deformation and functional coating presence [9].

4. Software architecture

Operating a large number of parameters at each step of discrete-event modeling system requires building a general program architecture and data storage model building to ensure efficient use of computing resources. Figure 2 shows system general view.

The operator sets irregularities parameters and their number. The system generates irregularities and transfers them to the data storage unit. After the transfer is confirmed, the selected surface creation algorithm is applied, which distributes the irregularities in the form of ellipsoid segments along the median plane of the surface. In this case, information about the coordinates of each irregularity centers
is added to the data warehouse. Next, it is necessary to set up the input parameters responsible for the contact interaction: the presence of a functional coating, microhardness, the given moduli of elasticity for both the coating and the half-space, set the boundaries of possible variation of characteristics, set up the step and the penetration limit.

![Program general architecture.](image)

Each implementation iteration generates data on the change in the characteristics of rough surfaces contact interaction. A data block is created containing new contact characteristics of the interacting segments. Depending on the penetration depth, their elastic or elastoplastic deformation is calculated. This process is repeated until the exposed deployment limit is reached. The data obtained at this stage is the core of the data storage unit. Secondary modules use them to simulate their own tasks and operate their own controller.

At the development stage, it is necessary to take into account the basic functionality of the software tool, expandability and the amount of resources spent on data processing. Taking into account the volume, concerns separation concept is used to more conveniently work with individual components. This allows you to differentiate the internal presentation of information from the ways it is accepted by the user. It is necessary to take into account the horizontal scaling of the system - the addition of new modules for simulating various contact interaction parameters.

5. Conclusion
As a result, the program with the described structure is a complete basic core for physical experiments system on contact interaction of rough surfaces using discrete-event computer modeling. The ability to create new and modify existing modules of the system allows you to flexibly customize the experimental logic for solving scientific and applied problems. The core of the system contains the basic logic of the rough surface formation and deformation, and the expandable data storage model through the controller allows using the results obtained to connect secondary modules for studying friction, wear, accelerated
testing, selection of the most suitable contacting materials depending on the requirements, calculation of joint thermal and electrical resistance and many others.

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