Three-dimensional of modeling microgeometry of contact pairs in technical systems

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Abstract. In this work, the technique of numerical simulation of the characteristics of contact pairs in technical systems is considered. The technique is based on the use of microgeometry parameters of the contacting surfaces. Based on the measurements of the surface roughness profile, the microgeometry parameters of the surfaces are determined. The technique described in the article allows to obtain a clear picture of the actual contact spots formation of the contacting surfaces, the size and volume of the intercontact area, the distribution of fields of equivalent stresses and temperatures in the contact pair.

In modern engineering one of the most important tasks is to ensure the required performance properties of the joints of contact pairs of aggregates and machines. Consideration of this topic is devoted to a significant number of publications. However, the contact characteristics of the components of the mechanisms, which ensure the operational properties of the connections, remain insufficiently studied. These characteristics, first of all, include the approximation of rough surfaces during operation, and the volume of gaps between them at the point of contact. They are interrelated and are determined both by the microrelief of the contacting surfaces and by the magnitude of the compressive pressures.

An analysis of the literature shows that surface roughness has long been considered as a key factor in solving contact problems. The performance characteristics of the contacting parts of the structure are directly determined by the contact properties of the mating surfaces. The processes of friction and wear occur on the actual contact area and depend not only on the material properties, but also on the pressure on this area, since the actual pressure determines the destruction of surface films and the occurrence of adhesive bonds on the contact.

Existing analytical methods make it possible to determine only the integral characteristics of a contact pair, and experimental studies are rather laborious and at the same time make it impossible to consider the whole set of changes in contact characteristics from the point of view of its microgeometry. Modern software systems of three-dimensional design and analysis in combination with experimental studies allow us to predict and obtain the characteristics of virtually any contact pairs for a fairly wide range of changes in the operational parameters of specific assemblies and mechanisms. At the same time, a numerical study of contact characteristics is based on the results of an experimental determination of the surface roughness of samples of contacting pairs. To build three-dimensional models of rough surfaces, it is necessary to have the parameters of their microgeometry, on the basis of which the simulation of a real rough surface is performed. The three-dimensional model of a rough surface in this case is represented by a set of protrusions having a regular geometric
shape and distributed in height so that the distribution of the material of the model corresponds to the
distribution of the material of a real rough surface [1].

Practically in all known works [2–4], wave functions are used to describe the surface roughness,
which in the future may negatively affect the calculation results. The analysis of profilograms of rough
surfaces shows that the profile of a rough surface is random, which cannot be described by a repeating
function. Therefore, the surface irregularities simulated by the method using wave functions will
incorrectly display the surface roughness, and, as a consequence, the actual contact area between the
modeled surfaces.

Currently, the microrelief of the contact surface is determined mainly by the characteristics of the
profile [5]. For this purpose, devices have been created that allow recording the profile of the surface
under study, and methods for processing profilograms have been developed [6, 7]. In the general case,
the microrelief characteristics of a rough surface do not coincide with the obtained profile
characteristics of this surface [8, 9]. The analysis of surface microrelief continues to present significant
difficulties even when analyzing data obtained using three-dimensional profilographs [10]. The use of
the main characteristics of rough surfaces does not allow to determine the true places of contact of the
contacting surfaces, as well as their relative position in the contact itself. Creating a three-dimensional
model of a rough surface that is closest to real, seems to be the most promising for its further use as a
base when performing contact characteristics calculations [11–14].

One of the methods that allow one to obtain a three-dimensional microgeometry and carry out
definition analysis is the technique described in [15]. The basic principle of this technique is that to
build a three-dimensional model, data from a real surface profilogram are used, and not average
roughness values. Knowing the exact distribution of microprotrusions over the entire contact surface is
crucial for calculating the contact characteristics of two rough surfaces. This distribution can be
obtained from the profilogram of the surface by sorting all points from the maximum to the minimum
value by the height of the microprotrusion and having measured the values along the base length.

Based on the data obtained from the profilogram of the surface (Figure 1), the method of
constructing a spline surface is used to construct its three-dimensional model, on the basis of which
the computational grid model is constructed (Figure 2).

![Figure 1](image_url)

**Figure 1.** Profilogram of a rough surface (arithmetic average deviation of the profile  Ra = 0.647).

After transferring the grid model to the strength analysis subroutine, appropriate boundary
conditions can be applied to it: the nature of the macro and microgeometry of the contacting surfaces,
the contact conditions (friction, slip), the pressure and temperature values at the site of contact, and the
thermophysical properties of the contacting materials. In this case, the interaction of two contacting
surfaces is considered as a linearly elastic problem of deforming a solid body with small deformations
and small displacements.

According to the results of the strength analysis, the values of equivalent stresses and inter-contact
pressure, the magnitude of the displacement (the amount of penetration of the surface of one part into
the surface of another) are obtained. In order for the three-dimensional model to adequately describe
the real nature of the contact in the areas of penetration, it is necessary to remove intersecting volumes
that appear as a result of mutual penetration.
As a result of this operation, we obtain a model of the actual contact area of two rough surfaces (Figure 3).

Figure 2. Mesh model of contacting surfaces.

Figure 3. The characteristic field of equivalent stresses on the surface of the contacting material in the event of a pressure being applied to the point of contact.

The method described above does not take into account the effect of the contact medium on the contact characteristics. The contact area can be defined as the space enclosed between the contacting surfaces. A grid model is also created for it, and the properties of the medium are set in the material parameters (Figure 4).

Figure 4. Mesh model of contact with the presence of the medium in the contact zone.
Such a technique for simulating surface microtopography also makes it possible to determine the parameters of intercontact volume, which, in turn, plays an essential role in a number of engineering practice problems. As an example, Figure 5 shows the model of contact volume and the distribution of the temperature field in it.

![Figure 5. Contact volume and temperature field distribution.](image)

The above-described method of numerical simulation of the characteristics of a contact allows to obtain a vivid picture of the formation of spots of the actual contact of the contacting surfaces, the size and volume of the intercontact area, the distribution of fields of equivalent stresses and temperatures in the contact pair.

References
[1] Demkin N 1970 Kontaktirovanie Sherohovaty Poverhnostej (Moscow: Nauka) p 277
[2] Lazarev V et al 2006 Matematicheskaya model’ sherohovatoj poverhnosti kontaktnogo tribospyrazheniya. Vestnik YuRGU. Mashinostroenie, 66 54
[3] Gryazev V 2013 Modelirovanie real’noj poverhnosti detalj. Izvestiya TulGU. Tehnicheskie nauki, 1 192
[4] Vojnov K, Khodakovskij V and Shvarcz M 2009 Matematicheskoe modelirovanie sherohovatyh poverhnostej Trenie, iznos, smazka 41 1
[5] GOST 25142-82 1982 Sherohovatost’ poverhnosti. Terminy i opredeleniya (Moscow: Izd-vo standartov) p 20
[6] Demkin N 1978 Topograficheskie harakteristiky poverhnosti i tochnost’ ih opredeleniya Mehanika i fizika kontaktnogo vzaimodejstviya 16
[7] Zavarise G, Borri-Brunetto M and Paggi J 2004 On the reliability of microscopical contact M. models Wear 257 229
[8] Izmailov V 1980 Correlation between surface topography and profile statistical parameters Wear 59 409
[9] Berkovich I 1977 Raschet statisticheskikh harakteristik sherohovatoj poverhnosti Mexanika i fizika kontaktnogo vzaimodejstviya 3
[10] Bengtsson A 1986 Poluchenie topograficheskogo izobrazheniya poverhnosti s pomoshch’yu profilografa Trenie i iznos 1 27
[11] Demkin N 2010 Zavisimost’ ekspluatacionnyh svoistv frikcionnogo kontakta ot mikrogeometrii kontaktiruyushchih poverhnostej Trenie i iznos 1 7
[12] Goryacheva I 2001 Mehanika frikcionnogo vzaimodejstviya (Moscow: Nauka) p 478
[13] Bhushan B 1998 Contact mechanics of rough surfaces intribology: multiple asperity contact Tribology Letters 4 1
[14] Bolotov A, Sutyagin O and Rachishkin A 2014 Komp’yuternoe modelirovanie topografii sheroхватых поверхности Mehanika i fizika processov na poverhnosti i v kontakte tverdyh tel, detal’ tehnologicheskogo i energeticheskogo oborudovaniya 729

[15] Ezhov A, Bykov L and Mesnyankin S 2018 Numerical Method for Determining the Real Contact Area of Contacting Bodies J. of Surface Investigation: X-ray, Synchrotron and Neutron Techniques 12 914