Assessment of the influence of contact surface roughness on thermal conductivity

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Abstract. The presented work describes a modified technique for numerical modeling the characteristics of contact pairs in technical systems, based on the use of microgeometry parameters of contacting surfaces. The microgeometry parameters of the contacting surfaces are determined according to the measurements of their roughness profile. The described technique allows one to reduce significantly the sample size of the values of local extrema of microprotrusions and microdepressions that have a real impact on the value of contact thermal resistance. The described technique can significantly reduce time and hardware costs and simplify the calculation procedure itself. In addition, the proposed methodology by introducing a specified sampling interval allows you to set the required level of accuracy at the initial stage.

1. Introduction

In modern engineering, one of the most important tasks is to provide the required operational characteristics of the contact pairs of units and machines [1-4]. Consideration of this topic is devoted to a significant number of publications. Nevertheless, increasing the reliability of the characteristics of contact pairs of mechanisms obtained by calculation remains one of the urgent tasks of designing nodes and assemblies of objects of the developed equipment. The main thermal characteristic of any contact pair is the area of actual contact of the surfaces and the volume of gaps between them [5-7]. They are determined by both the microrelief of the contacting surfaces and the magnitude of the compressive pressures.

Obviously, the surfaces of parts in the contact zone are never absolutely smooth and coincide in profile, i.e. contact spots and gaps form between the surfaces. The interaction of the thermal and mechanical properties of the contacting materials and the medium in the gap form an effect called thermal contact conductivity (TCC). In practice, the reverse TCC value is used —thermal contact resistance (TCR) [5].

The need to determine the TCR is primarily due to the fact that the temperature gradient that arises in the contact zone due to the presence of the TCR leads to uneven temperature expansion of the parts, which in turn leads to an increase in mechanical stresses and, as a consequence, to structural deformations.

Thus, the determination of the reliable value of the TCR is one of the most important factors in the design of thermally loaded units and assemblies. In order to guarantee the specified reliability of the contact during operation, as well as the safety margin for each of the parts in the assembly, to ensure
the holding force and tightness of the structure, it is necessary to ensure regular thermal conditions and optimal pressure values in the contact areas.

2. Method
One of the methods allowing to obtain three-dimensional microgeometry and conduct strain analysis is the technique described in [8]. The main principle of this technique is that to construct a three-dimensional model, the data of a real surface profilogram are used, and not the average roughness values. Knowing the exact distribution of the heights 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 surface profilogram by sorting all points from the maximum to the minimum value by the height of the microprotrusion and by dimensioning the values by the base length [9]. This technique allows you to conduct a thermomechanical analysis of the state of the contact zone and determine the TCR using limited time and hardware resources. The disadvantage of this method is the lack of accuracy in determining the TCR, since in processing the profilogram only the values of local protrusions and depressions are taken into account.

A modification of the described method consists in the development of an additional module of the calculation program for determining the effect of surface microroughness on the value of TCR. Based on the surface profile obtained by the method described above, a new profile is created containing only those points on the surface at which the derivative of the surface profile changes sign, i.e. when processing these points, only those values are taken into account in which the product of the difference with the current value and the difference with the previous value has a negative sign, i.e.:

$$(A[i+1] - A[i]) \times (A[i] - A[i-1]) < 0,$$

where $A[i]$ is $i$ cell of the array with data of profile height.

This selection allows you to save the original profile by highlighting the most likely intersection points with other surfaces and filtering out points that cannot come into contact. To fulfill this condition, it is proposed to introduce a treatment zone bounded by two boundaries parallel to the line drawn from one local extremum to another and separated by $+\delta$ and $-\delta$. Points lying between two local extrema within these boundaries, i.e. in the range $2\delta$ are not taken into account in the calculation (Figure 1).

![Figure 1. The boundaries of the processing area.](image)
3. Results and Discussion

The value of the range $\delta$ can be set manually, at the stage of importing the profile of the profilogram into the module of the calculation program. Thus, the accuracy of the calculation depends on the quantity $\delta$, and, consequently, the final result of the calculations. In this work, as an example, we calculated the surface profile with a roughness of $Ra = 2.08 \mu m$.

The value of $Ra$ is used as a reference parameter. The surface profilogram shown in Figure 2 (blue line) has 3200 elevation points. As a result of data processing with the parameter $\delta = 2.0 \times Ra$, the number of elevation points is reduced to 82. It should be noted that in the above example, when constructing the curve, the automatic interpolation method built into Microsoft Excel was used, which may slightly distinguish the resulting picture from the future model.

**Figure 2.** The result of processing the profilogram with $\delta=2,0\times Ra$ (red line).

Changing the value of $\delta$ to $1.5 \times Ra$ (Figure 3) leads to a decrease in the processing points to 150. Such an increase compared to $\delta = 2.0 \times Ra$ gives a suitable density and does not greatly complicate the calculation procedure. Figure 3 shows that the calculated curve better describes the existing roughness profile, which indicates the inclusion of points that accurately characterize the surface profile.

**Figure 3.** The result of processing the profilogram with $\delta=1,5\times Ra$ (red line).

A further decrease in the parameter $\delta$ to $0.8 \times Ra$ reduces the initial number of points to 321 (Figure 4). A similar description of the surface topography may already have an impact on the requirements for computing resources.
Figure 4. The result of processing the profilogram with $\delta=0.8 \times \text{Ra}$ (red line).

The best match between the calculated and initial microrelief is achieved with the parameter $\delta = 0.2 \times \text{Ra}$ (Figure 5). Despite the fact that the accuracy of the description in this case is the best and the calculated profile practically coincides with the original, the number of processed points is 584, which is $\sim 5.5$ times less than the original set. Accordingly, the requirements for required computing resources are increasing.

Figure 5. The result of processing the profilogram with $\delta=0.2 \times \text{Ra}$ (red line).

As an example, Figure 6 shows a point cloud and a three-dimensional surface model with the parameter $\delta = 1.5 \times \text{Ra}$.
4. Conclusion
The studies showed that when the same boundary conditions were set for different quality of the surface description, the pattern of formation of the real contact area and the heat transfer components in it changed significantly. Due to the fact that the heat flux in the contact of rough surfaces flows both through the actual contact points and due to re-radiation between the contacting surfaces [10], the influence of the actual contact area and the area and orientation of the re-emitting surfaces is decisive in determining the thermal conductivity of the contact.

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