Efficient Roughness and Small Wear

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Abstract. The reliability for the surfaces of friction directly depends on the shape and size of the roughness (and material of course) which there are on the surfaces of the mobile pair of friction (body and counter body). The movement even for the one part leads to detach small parts from the surface of friction. This process has the name wear/wear and tear or deterioration. Usually, this action is escorted with the physical phenomenon as the heating. In this case both the firmness and the wear resistance begin to fall/diminish essentially. In this article one important factor will be described in detail. It connects with the analysis how we can make all lugs in a roughness more stable during the real operation. Several ways will be demonstrated and described here. Moreover, applied calculations and figures confirm the theoretical positions as well. At last, some negative estimates during the processes of calculations and dimensions at the present time are given and the methods how to avoid them in practice using new achievements and recommendations.

1. Introduction
In technical literature there are rather many printed works in which authors broach the questions with a problem linked with the roughness and the ways about different calculations [1-9]. For example, they suggested to take into account the density of probability for the tangent of the angle in which practically each lug among the roughness has usually. This information isn’t sufficient as it will be explained further.

It is common knowledge, that the stable operation work will be essentially different if there are the next shape of roughness (figure 1).

![Figure 1. Different profiles of the surface roughness: contact with a profile №1 is undesirable.](image)

Moreover, it is not right to make the test-control of the roughness using special high-precise device only on the short length and in one plane. For this procedure we have to get 3D-representation but the next modern devices (for example, Hommel Tester T8000 Etamic, Hommel-Etamic WS, Hommel
Tester T1000 Basic, Hommel Tester W55, HOMMEL nanoscan 855 and Tecnai G2 30F U-TWIN STEM) don’t permit to get 3D-representation of the great surface at once.

2. Text №1. About roughness
Really any zone/places/points of contact for pair of friction between body and counter body can be quite different (figure 2).

![Diagram of contact areas](image)

**Figure 2.** There are three mutual area/square of contact: nominal $A_n$, contour $A_c$ and actual $A_r$ ($A_c = \Sigma \Delta A_c$ and $A_r = \Sigma \Delta A_r$) during the fixed position for pair of friction.

As the practice shows [1-5], that usually many designers take into account only two parameters to estimate the roughness, namely: $Ra$ and $Rz$, which strictly speaking are not sufficient a performance graphs. And really, if the isolated and single roughness has many shapes with different height, the different forms in a width and the same a declivity, then in this case we cannot understand what shape will be firmer during the operation.

Let’s look attentively at these formulas to calculate $Ra$ and $Rz$:

$$Ra = \frac{1}{l} \int_0^l |h(x)| \, dx,$$

where $l$ is the length/way of the measurement for the roughness on the surface (given with the function $h(x)$) of the part. So, $Ra$ is the average arithmetical deviation for the profile which is calculated from the average line for roughness.

Another parameter $Rz$ must be calculated to determine the average height for unevenness using for this aim five points which have the maximum height. In this case they apply the next formula:

$$Rz = \frac{\Sigma h_{\text{max}} + \Sigma h_{\text{min}}}{5} / 5.$$

In figure 1 the same obtained may be identical though really the shape and the heights of each roughness can be essentially various. Consequently, the strength against wear and tear will be essentially different.
To eliminate this shortcoming, it is needed to determine the centre of gravity for each shape in the roughness. Only in this case the common estimation of the strength against wear and tear will be good and right.

To confirm this fact let’s propose that there are two single and isolated roughness. The question is the next: which single roughness will be firmer if they have the different height (small and big) and the applied side force is the same? Evidently, the first roughness will have more reliability during the operation if it has the smallest height when the other performance graphs for the both roughness are the same (structure of material, chemical and physical properties and so on). Consequently, this is very important moment to make the right estimation and use in practice.

3. Text №2. Additional Formulas and Computer Calculations

In accordance with the expounded material above the next mathematical information and examples will be demonstrated. In particular, how to calculate the co-ordinate for the centre (C) of gravity in the common shape? Usually, the next formulas can be used if the body is similar:

\[
x_c = \frac{\int x \, dv}{V}; \quad y_c = \frac{\int y \, dv}{V}; \quad z_c = \frac{\int z \, dv}{V}.
\]

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Now let’s suppose that there is the next shape for the isolated roughness (figure 3).

\[ S_z = \int_y y \, dF = \int_y 2r \sin \varphi \, dy = \int_0^{\pi/2} r \cos \varphi \sin \phi \, dy = -2r^3 (\sin^3 \varphi / 3) \bigg|_0^{\pi/2} = 2r^3/3. \] (4)

Then the coordinate of the centre (C) of gravity will be the next:

\[ y_c = S_z / F = (2r^3/3) / (\pi r^2/2) = 4r / 3\pi. \] (5)

No problem to calculate centre of gravity if the shape of roughness has any other form (for example, as a triangle).

More important to get the smallest average height for the roughness and its peaks must not be sharp (only smooth and gently sloping).
4. Text №3. Computer Calculations and Decisions

Let’s suppose that after experiment connected with the procedure to fix the wear there were obtained the next meanings for the first test: \( y_1 = 0; 0.07; 0.18; 0.25; 0.29; 0.33 \) (the roughness had the profile as it was shown in Fig. 1, number 1). The second trial gave the next meanings about the wear: \( y_2 = 0; 0.05; 0.11; 0.18; 0.22; 0.27 \) (the roughness had the profile as it was shown in Fig. 1, number 2). The step/period between of each dimension was 5 hours (constant). For investigation the new test bench was used which makes the reciprocation movement for the pairs of friction \[6\]. Computer programme in the casing MathCad-15 \[7-10\] to solve this task is below.

\[
i : = 1 \ldots 6 \quad n : = 6 \quad h : = 5 \quad j : = 1 \ldots 6
\]

\[
y_{1i} = 0 \quad 0.07 \quad 0.18 \quad 0.25 \quad 0.29 \quad 0.33
\]

\[
y_{2j} = 0 \quad 0.05 \quad 0.11 \quad 0.18 \quad 0.22 \quad 0.27
\]

\[
x_i = 0 \quad 5 \quad 10 \quad 17 \quad 20 \quad 25
\]

\[
x_j = 0 \quad 5 \quad 10 \quad 15 \quad 20 \quad 25
\]

\[
Y_{10} = \sum_i \frac{y_{1i}}{n}
\]

\[
t_0 = \frac{x_1 + x_n}{2} \quad Y_{10} = 0.187
\]

\[
k_1 = n \cdot \frac{n^2 - 1}{12}
\]

\[
k_2 = n \cdot \frac{(n^2 - 1) \cdot n^2 - 4}{180}
\]

\[
t_0 = 12.5 \quad k_1 = 17.5
\]

\[
a_1 = \frac{1}{12 \cdot k_1} \left[ 3 \cdot \left( \sum_i y_{1i} \cdot (2 \cdot i - n - 1)^2 \right) - (n^2 - 1) \cdot \left( \sum_i y_{1i} \right) \right]
\]

\[
b_1 = \frac{1}{2 \cdot k_1} \left( \sum_i y_{1i} \cdot (2 \cdot i - n - 1) \right)
\]

\[
c_1 = Y_{10} - \frac{k_1 \cdot a_1}{n}
\]

\[
a_1 = -0.016 \quad c_1 = 0.234
\]

\[
Z_{1i} = \frac{(x_i - t_0)^2}{h^2} + b_1 \cdot \frac{x_i - t_0}{h} + c_1
\]

\[
Z_{1i} = -0.038 \quad 0.096 \quad 0.196 \quad 0.264 \quad 0.3 \quad 0.302
\]
For calculations the non-linear approximation (parabola) was applied (graph is in figure 4). The quantity of measuring: n = 6; the step of measuring is after each 5 hours.

Parabola’s parameters are a1, b1 and c1. Theoretical equation is \( Z_1 \).

![Graph showing three curves for the image of the processes linked with the deterioration.](image)

**Figure 4.** Three curves for the image of the processes linked with the deterioration: \( Z_1 \) describes the statistical data by means of the parabola approximation; \( y_1 \) – initial statistical data which were obtained by means of measurements (wear and tear for the roughness as it can be seen in figure 1, position number 1)); \( y_2 \) the process of wear if the roughness has the smooth shape (figure 1, position number 2).

Made approximation to describe the process of wear applying parabola formula gives very good accordance to the initial statistical data. And simultaneously we can see the striking disparity between for the velocity of wearing if the form of roughness profile has the shape number 2 against the shape number 1 (figure 1).

5. **Short Discussion**

Analysis of the technical literature connected with the wear process and with the ways of treatment the parts (as pairs of friction) shows that there were not such investigations and description with the computer programme as they are given in here.

These results will help to get smooth and gently sloping profile for the upper surface layer for each part in the friction mobile junction. It really diminishes both wear and tear during the operation and increases the reliability for many mechanical systems.

6. **Conclusion**

It is common knowledge, that the process of wearing usually has three stages:
1) Running in, when the rate of deterioration grows rather quickly and at this period the majority of high ledges for roughness begin to collapse. That’s why during mechanical machining it is needed to get on the whole only smooth and gently sloping ledges for the roughness;
2) Moreover, the centre of gravity must be the most below to the basic surface of the pair of friction.
   It’ll increase the resistance against the wear without fail and the reliability in the period of operation will be essentially larger;
3) Using the worked-out computer programme with non-linear approximation by the parabola equation there is the really possibility to get the right estimation of the wear resistance for the different mobile pairs of friction for the various mechanical systems.

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