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STATISTICAL TESTING OF THE MEASUREMENT ACCURACY OF MOBILE ROUGHNESS MEASURING INSTRUMENTS

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Abstract: Surface roughness is a very important factor influencing overall quality of products of modern industry. There are numerous methods of measurements of surface roughness. A very important group of roughness measurements instruments are mobile ones. They are particularly useful in measurements under industrial conditions. However, precision and accuracy of results obtained with the use of mobile instruments can depend on an operator. Therefore, the question is how accurate are measurements carried out with mobile instruments. The paper describes problems relating to measurements of roughness with mobile instruments. It also presents results of statistical testing of the precision and accuracy of a typical portable instrument.

Keywords: roughness, precision, measurement, mobile instrument.

1. INTRODUCTION

When designed, a machine element is assumed to be ideal in shape and texture. Thus, the geometry and dimensions of a workpiece need to be exactly the same as those specified in the design [1]. The surface too must be ideally smooth. However, numerous factors cause that the geometrical surface structure of a workpiece is characterized by certain irregularities. These irregularities lead to differences between the real and the nominal workpiece. Figure 1 shows the irregularity types.

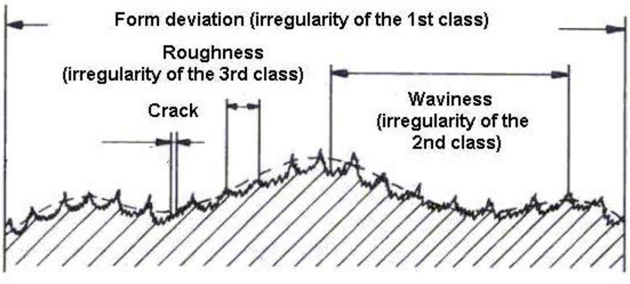

Fig. 1. Types of surface irregularities [2]

They include:

- surface roughness, which occurs when the distance between irregularities is about $5 \div 150$ times larger than their depth. Surface roughness is usually related to tool paths, for example, turning, grinding or finishing cuts [43].
- waviness, which is observed when the distance between irregularities is about $100 \div 1000$ times larger than their depth; in some sources the lower limit is 40 or 50. Waviness is usually a result of a disturbed manufacturing process [46], an example of which can be vibrations between the workpiece and the grinding wheel.
- form deviations are assumed to occur when the distance between irregularities is equal or more than 1000:1. Shape deviations are caused, for example, by guideway errors, errors of rotary elements, or by thermal expansion of elements.

It should be noted that cracks may also be considered a type of irregularity, for which the ratio between the distance and the depth is less than or equal to 5.

Surface roughness influences very significantly functional properties of machine parts [3]. Therefore, its measurement and evaluation is a very important field of modern metrology. Some researchers investigate influence of stylus tip and other factors on measurement results [4, 5]. Zawada-Tomkiewicz in [6] evaluates surface roughness parameters on the basis of the image of the machined surface. Grzesik in [7] investigates influence of the tool wear on roughness of surfaces turned with differently shaped ceramic tools. Zhengkai Zhang et al in [8] propose a new approach to the analysis of surface topography that is based on empirical decomposition of the profile.

Quinsat and Tournier in [9] describe a novel non-contact system allowing in-situ measurements of roughness of elements that due to their dimensions and mass cannot be measured at laboratory. Nowadays, due to development of 3-dimensional analysis of geometrical surface structure some researchers undertake efforts aiming at digitization of measurement results [10] and at the definition of parameters well describing 3-dimensional surface topography [11]

Generally, methods of measurements of surface roughness may be divided into two main groups: contact and non-contact ones. Mobile roughness measuring instruments are usually contact ones. They are compact, robust and easy to apply. The main advantage of this type of instruments is that they allow in-situ measurements under industrial conditions and the main drawback is that they are not isolated from harmful environmental conditions. One of the possible sources of the errors in measurements with use of mobile roughness measuring instruments are human errors. In this paper are discussed problems of statistical testing of the precision and accuracy of typical mobile roughness measuring instruments.

2. PROCEDURE

The instrument, which was used in the experiments is the typical mobile roughness measuring instrument, equipped with a inductive probe-head and the tip with a skid. The specimen to be measured was a roughness standard with precisely defined parameter Ra.

The plan of the experiment was following:

1. To carry out two series of 50 roughness measurements of the specimen, whose roughness parameters are known. The parameter to be investigated is Ra and both measurement series should be conducted under different measurement conditions.
2. To calculate mean values, standard deviations and ranges for results of both measurement series. After calculations we obtain following parameters:

$\overline{Ra}_1$ - mean value of the parameter Ra from the first series of measurements,

$\overline{Ra}_2$ - mean value of the parameter Ra from the second series of measurements,

s_1 – standard deviation of the measurement results in the first series of measurements,

s_2 – standard deviation of the measurement results in the second series of measurements,

R_1 – the range of the measurement results in the first series of measurements,

R_2 – the range of the measurement results in the second series of measurements.

3. To compare mean values $\overline{Ra}_1$ and $\overline{Ra}_2$ by the statistical test and evaluate if the difference between them is statistically significant [12]. The test will be conducted with use of the following equation:

$$t = \frac{\overline{Ra}_1 - \overline{Ra}_2}{\sqrt{\frac{s_1^2 + s_2^2}{n}}} \quad (1)$$

where n is the number of measurements in each series. (in the experiment n=50). Assumed level of significance for the test is 0.01.

4. To evaluate repeatability of measurement results. As a measure of the repeatability to take value

$$s = \max(s_1, s_2) \quad (2)$$

5. To evaluate expanded uncertainty of measurements from the equation

$$U = u \cdot s \quad (3)$$

where U is the expanded measurement uncertainty, u is the coverage factor and s is the standard deviation given by the equation (1). The probability level considered in the experiment is P = 0.95.

6. To evaluate measurement bias in both measurement series from equations:

$$e_1 = \overline{Ra}_1 - Ra_{true} \quad (4)$$

$$e_2 = \overline{Ra}_2 - Ra_{true} \quad (5)$$

where Ra_{true} is the real value of parameter Ra of tested specimen.

For further consideration this value of the error is taken, whose absolute value is higher.

7. To evaluate accuracy of the instrument from the equation:

$$\delta = \left| \frac{e \pm U}{W_{\max}} \right|_{\max} \cdot 100\% \quad (6)$$

where e is given by equations (4) and (5), U is given by the equation (2) and W_{max} is the measuring range of the instrument [12].

3. EXPERIMENT

The experiment involved measurements of an irregular roughness standard produced by Hommelwerke Company. The value of the parameter Ra for the standard is equal to 0,67 μm. The photograph of the standard is shown in Fig. 2.

Fig. 2. Roughness standard used in the experiment

Measuring instrument used in the experiment was a portable roughness measuring instrument Hommel Tester T1000 by Hommelwerke. Hommel Tester T1000 is a mobile device allowing performing in-situ roughness measurements. The instrument is shown in Fig. 3.

Fig. 3. Roughness measuring instrument used in the experiment – Hommel Tester T1000 by Homelwerke

In the table 1 there are given basic technical specification of the instrument Hommel Tester T1000.

Table 1. Basic technical specifications of the Hommel Tester T1000

Measurement type	Skid measurement
Filter	Gauss digital filter
Traverse length lt [mm]	0.48/1.5/4.8/15; max. 16
Sampling length ln [mm]	1.25/4.0/12.5
Cut off λ [mm]	0.08/0.25/0.8/2.5/8.0
Measuring range	80 μm
Diamond stylus tip	5 μm 90°
Skid radius	lengthways 30mm/tranversal 1.9 mm

There were two series of 50 measurements carried out under reproducibility condition of measurements. In the described experiment both series of measurements performed by different operators on different days. The first operator was not skilled at performing measurements in order to establish if operator's experience can influence results. Both series were carried out with the use of the same traverse and cut off length (traverse length lt = 4.8 mm and cut off length λ = 0.8 mm). In the experiment the value of the roughness parameter Ra.

4. RESULTS AND DISCUSSION

Measurement results obtained in the experiments are shown in Fig. 4 and Fig. 5.

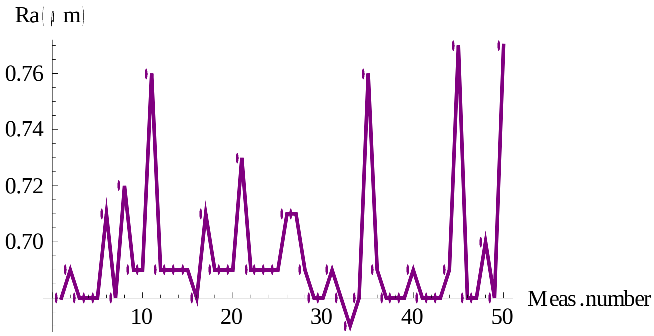

Fig. 4. Ra values obtained in the first measurement series

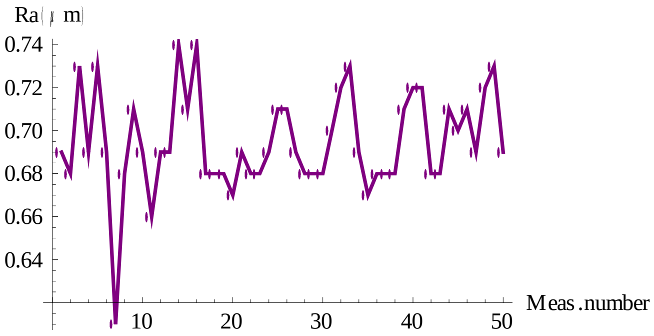

Fig. 5. Ra values obtained in the second measurement series

Mean values of the parameter *Ra* from obtained in both series of measurements are following:

- for the first series: $\overline{Ra}_1 = 0.695$ μm,
- for the second series $\overline{Ra}_2 = 0.6948$ μm.

In order to present a distribution of the results histograms were generated that are shown in Fig. 6 and Fig. 7.

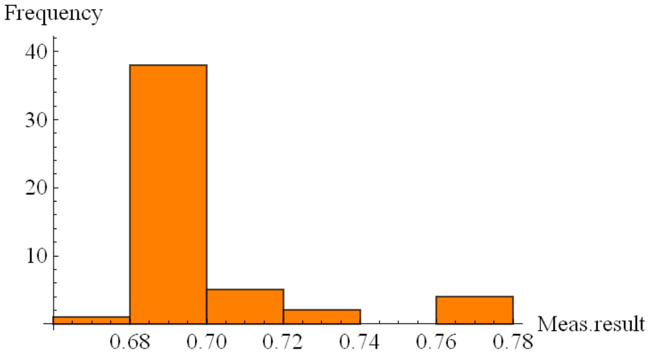

Fig. 6. Histogram of the results obtained in the first measurement series

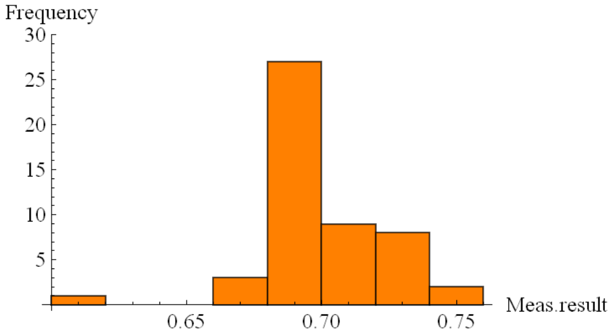

Fig. 7. Histogram of the results obtained in the second measurement series

Standard deviations *s* in both series of measurements are as follows:

- for the first series: $s_1 = 0.0344$ μm,
- for the second series $s_2 = 0.0338$ μm.

Ranges of measurement results *R* in both series of measurements are:

- for the first series: $R_1 = 0.1$ μm,
- for the second series $R_2 = 0.13$ μm.

In order to establish if difference of *Ra* values obtained in two measurements series is significant a statistical test was conducted with the use of the equation (1). The value *t* calculated from the equation (3) is $t = 0.0293$ whereas the critical value t_α taken from a statistical table is equal to $t_\alpha = 1.96$. Since $t < t_\alpha$ the difference between the values $\overline{Ra}_1$ and $\overline{Ra}_2$ is statistically negligible.

The next step of the analysis of obtained results was an evaluation of the measurement repeatability. As a measure of the repeatability a value of a standard deviation was taken. According to the procedure described in the previous section the measurement repeatability *s* is equal to the standard deviation of results obtained in the first measurements series, i.e. $s = 0.0344$ μm.

The value of the measurement repeatability was then used to calculate an expanded uncertainty of measurements according to the equation (3). The expanded uncertainty *U* for the probability level $P = 0.95$ (for which a coverage factor $u = 1.96$) is equal to $U = 0.0674$ μm.

Relatively large number of measurements allowed to evaluate measurement bias. Assuming that mean value of the parameter *Ra* from both series is equal to 0.695 μm the measurement bias *e* calculated with the use of the equations (4) and (5) is: $e = 0.025\,\mu\text{m}$.

Finally, the accuracy class δ of the instrument was evaluated with the use of the equation (6). It was calculated taking into account values of the instrument repeatability and the measurement bias. Assuming probability level P = 0.95 the accuracy class of the instrument Hommel Tester T1000 is equal to $\delta = 0.12\%$

An analysis of experimental data shows that there are not any significant differences between results obtained in two measurements series. The mean values of *Ra* in both series are very similar. This observation has been confirmed by the result of the statistical test. The repeatability error and the range in both series are quite similar, too.

The analysis showed that a slight systematic error may occur. Its measure – the bias – is equal to +0.025 μm. The bias was similar in both measurement series. However, it should be noted that its value is relatively low (it is a little less than 3 %). The value of measurement uncertainty reached about 0.07 μm and it is relatively low, too.

Obtained results show that the accuracy of the instrument is quite high. This observation has been confirmed by the evaluation of the accuracy class of the applied Hommel Tester T1000. Calculated value $\delta = 0.12\ \%$ allows to include this instrument to the laboratory devices and it can be considered as a reference one.

6. SUMMARY

It is estimated that about 90 % of all failures of machine parts are initiated due to surface damages such as fatigue or stress corrosion cracking, wear, erosion, etc. Therefore measurement of surface roughness is a very important branch of metrology of geometrical quantities. Surface roughness measurements may be performed with the use of numerous methods. These methods may be generally divided into two main groups: contacting techniques and non-contacting ones. In the group of mobile devices that allow performing in-situ measurements contacting methods are dominant. In the paper a contact roughness measuring instrument Hommel Tester T1000 by Hommelwerke was investigated. The instrument is equipped with a inductive measuring head and a skid. It is mobile, compact and easy to apply, but the question was it measurement results obtained with the use of this instrument are reliable and comparable. Therefore the experiment described in the section 3 was conducted. It involved performing two series of measurements of a roughness standard. There were fifty measurements in each series and both series were conducted by different operators at different days. The measuring head was hand-held during the measurement. One of the operators was a novice and one an expert in roughness measurements in order to establish if operator's experience influences significantly measurement results. It turned out that there are not any significant differences between the results obtained by the operators. It proves that even inexperienced operator can perform accurate roughness measurements with the use of the investigated instrument.

An analysis of measurement results showed that a slight systematic error occurs. Its measure, the bias, was equal to about 3% of the true value. In order to investigate the if the value of this error is constant or it can change, the next experiment involving measurements of different standards should be carried out. In the next experiment the accuracy of the instrument can be also evaluated with the use of other procedures, for example, those described in [13] and [14].

Generally, obtained results show that the instrument is very accurate. The calculated value accuracy class $\delta = 0.12\ \%$ proves that the investigated instrument can be even regarded as a reference one in the laboratory. Considering the fact the instrument is dedicated mainly to the in-situ measurements under industrial conditions it is a very good result.

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