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The analysis of credibility and reproducibility of surface roughness measurement results

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ABSTRACT

The paper describes results of a project: *The analysis of credibility and reproducibility of surface roughness measurement results*. This research was made in five university research centers and five Polish industrial laboratories (car and aircraft engines and engine parts, bearings). All the parties that took part in the project were equipped with laboratory profilometers on which measurements were performed. For comparison purposes samples after typical finishing operations were selected, i.e. after honing, grinding or super finish. Several measurement standards were used as well. The project proved that measurements of roughness provide different results and requires further work to find good explanations and reasons of these differences. This would help to improve analysis of surfaces and eliminate discrepancies of roughness measurements. Research conducted on profile measurements gave unsatisfying results because of high parameter variability. It can effect in finding better reasons to introduce three-dimensional surface measurements in Polish industrial laboratories, because they are more representative of the surface topography.

1. Introduction

Surface roughness measurements of any workpiece are among the most important ones in length and angle metrology, both in theory, and practice. Results of these measurements have very large divergences because of large variety of instruments for surface roughness analysis. The values of these differences are often difficult to qualify, various measuring instruments use various algorithms of profile processing like calculation of reference elements or filtration of the acquired signal.

The idea of the project emerged at one of research—industry meetings, with a question: what differences in parameter values can we expect measuring the same surface a number of times with difference devices? Who is right when a supplier proves that roughness specifications measured at his site are below limit values while his customer gets results above these limits? As that situation happens quite often we decided to do test measurements to get a clear idea and conclusions that could be used in quality control. The project titled *The analysis of credibility and reproducibility of surface roughness measurement results* was completed in 2007 [1]. This research was made by five university research centers and five industrial laboratories located in Poland. The research places were located at: Poznan University of Technology, Koszalin University of Technology, Lublin University of Technology, Warsaw University of Technology and Kielce University of Technology, while industry involved in the project were: MAHLE Krotoszyn (manufacturer of cylinder liners), NSK ISKRA Kielce (manufacturer of bearings), Pratt & Whitney Kalisz (manufacturer of aircraft engines), FLT Krasnik (manufacturer of bearings), Volkswagen Motor Polska Polkowice (manufacturer of car engines) [2]. The above mentioned laboratories used the following measurement devices: Form Talysurf 830 PGI, Perthometr S2, Hommel Tester T8000, Form Talysurf 120i, Form Talysurf 2, Form Talysurf PGI, Perthometer S8P. All these instruments were based on mechanical stylus principle; this allows to have theoretically the same measurement condition.

Temperature in particular laboratories was not specified, however what was required from participant was to have 'proper laboratory conditions' maintained. During measurements each laboratory had a temperature between 18 and 22 °C, and gradient not exceeding 2° per hour and per meter. Test sites were not informed about results from other labs, they also did not know about expected values neither regarding standards nor samples.

Similar investigations in relation to 3D parameters were recently done in European laboratories. Condeco et al. [3] checked relocation stage for different roughness measuring instruments (optical and tactile) comparing obtained results. They proved to be very close to each other (cross-correlation coefficients were ranging from 0.92 to 1, while difference statistical surface roughness

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parameter *Sq* reached only 1.3% and extreme surface roughness parameter *Sz* 3.6%, respectively). Sacerdotti et al. presented studies concerning variability in the three-dimensional measurement of autobody steel panel surfaces [4], that followed their previous experiences with electron-beam and electro-discharged textured surfaces [5]. Here, the work was done by a consortium of European industrialists and academics and was concentrated on influences of roughness on pressing and painting performance mainly as AUTOSURF project [6]. Their first study conducted on two-dimensional measurements gave unsatisfying results due to high parameter variability and in order to ascertain the causes they decided to concentrate on three-dimensional measurements. Considering measurement results the authors showed repeatability as a main issue for three-dimensional measurements. The main source of measurement variability proved to be software, as algorithms used to calculate various parameters, although based on the same mathematical equations, are implemented differently by different manufacturers. From that time software standards were implemented to check that issue so meaning of algorithms variations (particularly for new instruments) should be smaller.

2. Preparation of samples

Five samples were used for investigations (numbered from 1 to 5) to represent surfaces after some typical finishing machining processes: electrochemical polishing (sample no. 1), plateau honing (sample no. 2), super-finish (sample no. 3), grinding (bearing track, sample no. 4) and high-speed milling (sample no. 5).

For the above mentioned samples, the following parameters [7,8] were calculated and evaluated: Ra, Rq, Rz, Rt, Rdq, Rsk, RSm, Wt, Pt, Rk, Rpk, Rvk, Mr1, Mr2. These parameters were chosen as a set that was a compromise representing wishes of every party in project. They are understood as:

Ra—arithmetic mean deviation of the assessed roughness profile;
Rq—root-mean-square (RMS) deviation of the assessed roughness profile;
Rz—maximum height of the roughness profile within a sampling length (for that Rzi are computed on each sampling length and then averaged to get the Rz);
Rt—total height of the profile on the evaluation length (Rt is defined on the sampling length and it represents the height between the highest peak and the deepest valley);
Rdq—root-mean-square (RMS) slope of the profile within a sampling length;
Rsk—skewness (asymmetry) of the assessed profile;
RSm—mean width of profile elements, within a sampling length;
Wt—total height of the waviness profile on the evaluation length;
Pt—total height of the primary profile on the evaluation length;
Rk—kernel roughness depth (roughness depth of the core);
Rpk—reduced peak height (roughness depth of the peaks);
Rvk—reduced valley depth (roughness depth of the valleys);
Mr1—upper material ratio;
Mr2—lower material ratio;

For standards where Rmax parameter was specified it was considered as:

Rmax—height difference equal to the maximum of height differences computed on each sampling length.

An important part of the research was to ensure repeatability of measurement, and therefore, before samples measurement all instruments were calibrated with a set of standards. As machined surfaces can vary significantly in different places [9,10] a certain area was picked and clearly marked before measurement, to avoid problems with different results after measuring in different places. This area was previously tested and chosen as satisfactorily homogenous. Measuring conditions (pick-up parameters: 2 μm radius and 90° angle, speed of 0,15 mm/s, Gaussian filter, etc.) were predefined and every laboratory taking part in the research was obligated to set it the same way. Measured profiles were chosen within marked area and participants were advised that should possibly cover its whole range in Y direction (perpendicularly to drive unit axis). As not all of the labs were equipped with CNC positioners for horizontal movement in Y distance between profiles was selected individually by every participant, thus ensuring random conditions of measurement, typical for supplier–customer situation.

3. Results of measurements on standards

Comparative analysis of instruments consisted of calibration with 4 standards: type A2, D2, C3 and D1 according to ISO 5436 part 1. The results are shown in Table 1, with nominal value, tolerance limits and measurement results. The values exceeding assumed range are marked with bold italics.

Out of 10 instruments calibrated with standard A2, five exceeded ±5% of nominal values. Respectively, for C3 standard one laboratory had a device exceeding tolerances. The acceptable values of the deviation also in 1 case exceeded ±8% tolerances for D1 standard. 10% of tolerance limits were exceeded on D2 standard (the smallest values of height parameters) for 6 laboratories. Only 3 laboratories successfully fulfilled all the tests on standards. Tolerance limits for all the standards were given according to specifications of their manufacturers. From the 3 labs that fulfilled all the tests on standards one was industrial and two were from universities. On the other hand, the biggest differences was observed for research labs, leaving all industry somewhere in the middle.

4. The results of samples measurements

The measurements of samples were executed in 30 parallel sections and 14 roughness parameters were calculated from these traces. Generally sampling lengths selected for measurements were 0.25 mm, 0.8 mm, 2.5 mm, for samples nos. 1, 3, 4, 5; sampling lengths of 0.8 mm, and 0.25 mm were chosen, for sample no. 2, −0.8 mm, 2.5 mm, while for sample 3 due to small measurement area only one sampling length of 0.25 mm was selected.

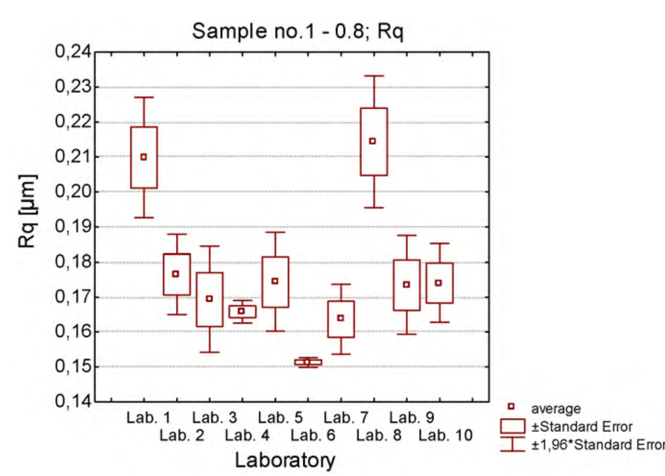

Fig. 1. Example of the results for parameter Rq with mean value (sample no. 1, sampling length 0.8).