THE PROBLEM OF ACCURACY IN ROUGHNESS MEASUREMENT WITH THE USE OF THE FORM MEASURING MACHINE TALYROND 365

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Abstract:

Accuracy of roughness parameters measured with Talyrond 365 was examined with comparison to the results received with the Form Talysurf PGI 830. The research has shown that there are several limitations of measurement method and software as well, while measuring with the Talyrond 365. Also, there are significant differences between results acquired with machines under comparison. The reasons for observed dissimilarities were discussed.

Keywords: Form Tester, Accuracy, Roughness

1. INTRODUCTION

In recent years some advanced models of form measuring machines, such as the Talyrond 365 by Taylor Hobson, have been enhanced with new features to enable surface finish examination. Unfortunately, users are not provided with information about the accuracy of roughness measurement on these instruments.

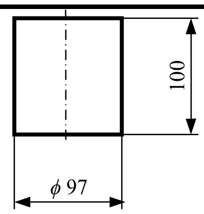
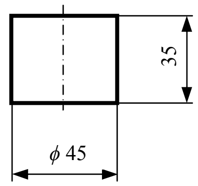
Calibration, testing and comparing the different roughness measurement instruments remain demanding issues of metrology for a long time [1, 2]. Verification of accuracy of machines that combine both form and roughness measurement is even more problematical.

Since no details concerning the procedures and accuracy of surface finish measurement were received from the Talyrond 365 (TR 365) manufacturer, it was found necessary to assess repeatability and reproducibility of roughness measurement experimentally. To do so, some comparative investigations using the Talyrond 365 and the Form Talysurf PGI 830 profilometer were undertaken. Both machines use tactile technique, they are made by the same manufacturer and are provided with the similar *Ultra* and *TalyMap* software, but they differ a lot in terms of structure.

2. MATERIALS AND METHODS

Due to the lack of cylindrical roughness standards, two regular cylindrical specimens, with symbols P01v and P02v respectively, were selected for comparative measurement. They differ in their size, hardness and surface roughness. The detailed information concerning these specimens is shown in Table 1. Both of them were measured in longitudinal direction (evaluation length equals to 4 mm). Because of distinct construction of measurement devices to be compared, the different specimen placements were applied. They are presented in Fig. 1. The red arrows represent the machine movement, while the violet ones refer to the measurement direction.

Table 1: Specimen features

P01v	*P02v*
	
• Type: light-wall tube (external surface measured) • Material: mild steel	• Type: turned shaft • Material: hardened steel

a)

b)

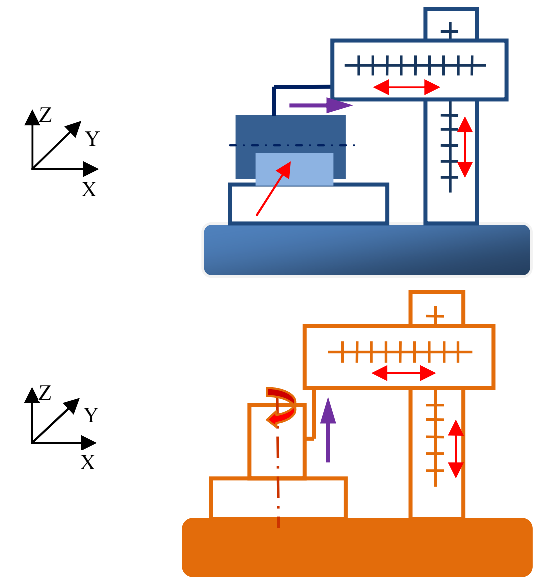


Fig. 1: Specimen positioning: a) Form Talysurf PGI 830, b) Talyrond 365

It ought to be mentioned, that the multiplied longitudinal measurement (*Cylinder map*) is probably the only way to acquire information about the roughness of profiles parallel to a spindle axis on the Talyrond 365. As this method demands measuring at least two profiles, it extends measurement time comparing to the PGI 830.

Three profiles (series) of each specimen were measured ten times with both devices. It was done in order to examine measurement repeatability of results received with the Talyrond 365, taking surface non-homogeneity into consideration. Such a method is based on the ISO recommendations [3]. The spacing between profiles was set to 1° for the Talyrond 365. The equivalent values for the Talysurf PGI 830 0.85 mm (P01v) and 0.36 mm (P02v).

These different values result from varying machine constructions and diameters of specimens.

There are dozens of roughness parameters which are calculated with ***Ultra*** and ***TalyMap*** software. It was decided to focus on a reasonable number of the most widespread parameters that give diverse information about the surface properties. As a result, four parameters were taken into consideration - from amplitude *(Rq, Rz),* horizontal *(RSm)* and hybrid *(R∆q)* group.

3. RESULTS AND DISCUSSION

3.1 Introductory Measurement

A substantial trouble with *Cylinder map* usage is to set the proper number of *Points to export*, as it can vary from 100 up to 999 999 and the manufacturer has not provided user with information concerning the criteria of this parameter choice. Due to this, a preliminary investigation for each of specimen was undertaken: during consecutive measurements of the same profile a different number of *Points to export* was set. Some received results are shown in Fig. 2 and 3. Blue lines illustrate results from the Talyrond and the red ones stand for the reference result obtained on the Form Talysurf PGI 830.

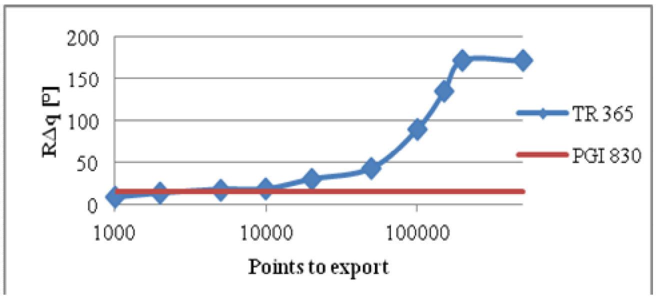


Fig. 2: Impact of number of *Points to export* on *R∆q* value

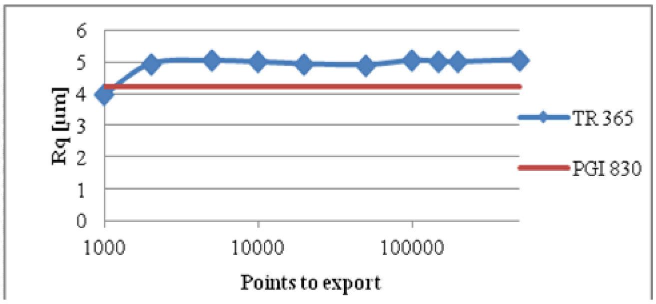


Fig. 3: Impact of number of *Points to export* on *Rq* value

As we can see, increasing number of exported points over 10 000 leads to incredible overestimating *R∆q* value (Fig. 2) and does not have significant impact on the *Rq* parameter (Fig. 3). Relations between the number of exported points and measurement results for parameters *Rz* and *RSm* are similar as given for *Rq*, so they are not presented. In the same time, increasing number of points over 100 000 makes computing noticeably slower. Also, according to the ISO standard [4], the minimum number of profile points should be no less than 10 000. Taking the results of experiments and the ISO recommendation into account, it was decided to perform further analysis with 10 000 *Points to export* applied.

3.2 Impact of Instrument and Scan Speed on the Roughness Parameters

To examine influence of scan speed on the measurement results a few values of stylus tip speed were used: v_1 = 0.5 mm/s (both devices), v_2 = 1 mm/s (both devices), v_3 = 2 mm/s (PGI 830) and v_4 = 2.5 mm/s (Talyrond 365).

To receive comparable measurement results, the same filtration method was applied for both instruments. It was Gaussian filter (ISO 11562:1998) with a cut-off length λ_c = 0.8 mm and λ_s = 0.0025 mm.

A set of summarized data that illustrates results for P01v specimen from two machines is given in Tab. 2. The symbols $\bar{x}$ and *s* stand respectively for mean value and standard deviation calculated from ten measurements of approximately the same profile. Similar chart was made for P02v.

Table 2: Roughness parameters measured with two machines; P01v specimen

Talyrond 365						
	Series 1		**Series 2**		**Series 3**	
Rq [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	5.128	0.104	4.863	0.054	5.009	0.105
v_2	5.019	0.055	4.919	0.058	5.012	0.066
v_4	5.240	0.046	4.810	0.071	5.046	0.032
Rz [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	21.380	0.312	20.380	0.155	21.000	0.411
v_2	21.030	0.177	21.070	0.503	20.960	0.320
v_4	21.480	0.339	20.690	0.803	21.520	0.388
RSm [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	189.90	4.91	204.80	5.14	186.90	8.63
v_2	186.60	3.69	198.20	6.00	184.10	8.02
v_4	199.40	5.58	196.00	11.14	174.20	8.22
R∆q [°]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	18.86	0.31	18.68	0.12	18.77	0.29
v_2	18.75	0.36	19.02	0.25	18.92	0.19
v_4	19.59	0.14	19.37	0.41	19.54	0.31
Form Talysurf PGI 830						
	Series 1		**Series 2**		**Series 3**	
Rq [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	4.394	0.001	4.090	0.006	4.131	0.026
v_2	4.395	0.002	4.119	0.006	4.121	0.003
v_3	4.395	0.012	4.119	0.005	4.118	0.008
Rz [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	17.330	0.006	18.015	0.014	16.701	0.011
v_2	17.371	0.024	18.183	0.019	16.739	0.038
v_3	17.377	0.090	18.343	0.039	16.871	0.745
RSm [µm]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	217.70	0.02	204.77	0.05	190.40	0.01
v_2	215.40	0.05	204.79	0.02	190.43	0.04
v_3	214.18	0.06	212.80	0.05	190.42	0.03

RΔq [°]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
v_1	13.65	0.01	13.41	0.02	14.72	0.02
v_2	14.02	0.02	14.22	0.02	15.15	0.05
v_3	16.44	0.74	17.15	0.29	17.36	0.58

As between consecutive measurements on the Talyrond the specimen turns around the table axis, it is practically impossible to assure that exactly the same profile is examined during repetitions. In effect, relatively high values of standard deviations for a single series were observed, while measuring on this device. On the contrary, measuring the same profile on the Form Talysurf PGI 830 does not present any problem. That explain, why standard deviation of some parameters obtained with Talysurf could be as low as single nanometre or even its fraction.

The results presented in Tab. 2 show evident disparities of mean values found with various instruments for all velocities. Total mean values calculated for all series and all measurement velocities are given in Tab. 3. This chart shows that *RSm* received with the Talyrond is 6.6% lower than with the Talysurf, while total mean values of other parameters are significantly higher than ones measured with the PGI 830. The biggest relative difference (26%) is observed for the hybrid parameter *RΔq*. When the P02v specimen is taken into consideration, this dissimilarity is even larger: 39.6% (Tab. 4).

Table 3: Results of ANOVA for P01v

	Rq	Rz	RSm	RΔq
TR365	5.01 µm	21.06µm	191.1 µm	19.06 °
Talysurf	4.21 µm	17.50µm	204.5 µm	15.12 °
percentage change	18.9%	20.3%	-6.6%	26.0%
p-value velocity	0.61	0.23	0.48	3.4E-55
p-value machine	3.3E-87	1.47E-92	1.7E-13	9.8E-114

Table 4: Results of ANOVA for P02v

	Rq	Rz	RSm	RΔq
TR365	1.14 µm	4.70 µm	150.24 µm	9.70 °
Talysurf	1.19 µm	4.95 µm	149.30 µm	6.95 °
percentage change	-3.6%	-5.1%	0.6%	39.6%
p-value velocity	2.2E-04	3.4E-05	4.8E-08	1.7E-110
p-value machine	1.05E-39	2.1E-30	0.424	1.8E-146

However, as a specimen surfaces were non-homogeneous, the observed differences could have been interpreted as random. To explain results more profoundly, the two-factor analysis of variance was performed. The measurement device and scan speed stood for ANOVA factors. The analysis was performed separately for each specimen and each roughness parameter. For every combination of device and speed were 30 measurements (ten repetitions for each of three series). The probability values given in a bottom row of Tab. 3 provide evidence that for P01v the differences between mean values acquired with both instruments are very significant ($p<<0.05$). Similar analysis carried out for another specimen showed that both amplitude and hybrid parameters differ meaningfully. The only exception is *RSm* parameter, where the difference is not significant ($p> 0.05$).

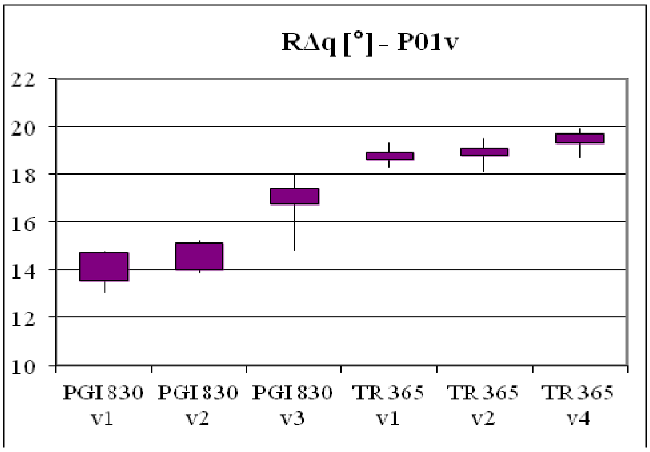


Fig. 4: Specimen P01v – impact of a stylus tip speed and measuring device on parameter *RΔq*

Moreover, ANOVA investigation proved that a scan speed is statistically important for all parameters of a smoother surface (P02v). Also, this correlation is crucial, when the hybrid parameter of another specimen is acquired. For the faster scan speed *RΔq* values are considerably higher. All these relationships are relevant to the fact, that when high speed is applied, a tip may round sharp peaks and cannot penetrate valleys properly .

It cannot remain unmentioned that the scan speed has no impact on the standard deviation of horizontal and amplitude parameters performed with both instruments. However, it can also be observed that for *RΔq,* the higher speed of the PGI 830 tip movement, the higher standard deviation values are. In the same time, there is no relation between these two parameters while measuring with the Talyrond 365.

The relationship between a scan velocity, instrument type and parameter values is presented in Fig. 4. Similar box-whisker plots were received for other parameters and specimen.

Among other reasons for the differences in the values given for both instruments, there should be mentioned not only the different measurement method, but also the accuracy of the mechanical parts of both devices. As the specifications show, the straightness deviations of both arm and column of the Form Talysurf PGI 830 get lower values than the referring ones of the Talyrond 365.

What is more, it should be taken into consideration that compared machines have completely different gauges. While in the TR 365 the inductive one is used, it is replaced with a phase grating interferometer in the PGI 830. The second of mentioned gauges has not only higher resolution and range, but also its linearity is significantly better. It must have had affected the accuracy of measurement.

Not less important factor affecting the measurement results is stylus size and shape, as they differ for both devices. A comparison of styluses used is presented in Tab. 5.

Table 5: Stylus used in research

	Talyrond 365	Form Talysurf PGI 830
Type	Conic (112-3806)	Conic (112/3227)
Arm length	100 mm	60 mm
Radius	5 µm	2 µm
Angle	90 °	60 °

The ISO standard [4] recommends that for the cut-off length used in research, a maximum stylus radius should not be over 2 µm, but 5 µm may not cause significant differences in results. However, the effect of low-pass filtering by a stylus tip was observed while measuring with the Talyrond 365. To make matters worse, as a stylus tip description claims: *The standard instrument specification may be degraded when using this stylus,* a manufacturer of the TR 365 seems to be aware of the specific negative impact of the stylus used with the TR 365 on the instrument specification and, in consequence, measurement results. However, no additional information concerning both kind and degree of this influence is given.

Moreover, the data spacing and acquisition of profile points with the Talyrond 365 affect the final results. As it was shown in 2.3, there is a significant link between the measurement settings and values of roughness parameters. Also, after-measurement digital resampling modifies a profile and, in effect, also values of parameters. It clearly shows that while measuring with the Talyrond 365, the user's experience and consciousness are crucial for the measurement and profile analysis results, especially when hybrid parameters are required.

Also, the statistically significant trend ($p < 0.05$) for *Rq* values was observed while measuring on the Form Talysurf PGI 830. As temperature in the laboratory was stable, it is assumed that this trend is associated with the surface damaging on the micro-scale, caused by stylus tip sliding across the specimen. Similar and even stronger tendency was observed, when measurement with the Talyrond 365 was performed. On the specimen made of the mild steel, even for the lowest stylus tip force, the surface was scratched. It shows, that the Talyrond 365 should not be used for measuring specimen made of mild materials.

Last but not least, software may have a significant impact on roughness parameter values. In spite of the fact, that the parameters calculated with Ultra and TalyMap software have the same definitions (according to the ISO standards), there is no information, concerning their algorithm implementations, given. As a result, not only parameters can be calculated in separate ways, but also the filtered profile and its mean line equation may not be the same.

4. CONCLUSIONS

The Talyrond 365 may be a cost-effective instrument to combine both form and roughness measurement, provided with user awareness of its limitations and their potential consequences for the values of parameters.

Firstly, the measurement of a single profile is more complicated and time-consuming, when compared to the Form Talysurf PGI 830. However, it ought not to be perceived as a machine drawback when roughness and form measurements of several profiles are combined. Then, a total time of measurement is reduced.

It also requires outlining that neither should the TR 365 be used to measure specimen made of mild materials, nor be completely relied on, when the values of hybrid parameters are obtained.

Furthermore, there may be a meaningful impact of a scan speed on the hybrid roughness parameters, but it is common for all profilometers based on contact measurement methods. In consequence, it should not be perceived as a drawback of the TR 365 itself, but it shows that user awareness of this relationship is required.

On the other hand, the most important difficulty in ensuring credibility of the Talyrond 365 is connected with the aftermath of its extra-ordinary "user-dependency". Not only does not the instrument limit the impact of the user settings on the measurement results, but it even requires choosing an appropriate value of number of points to be exported in order to perform properly, as it was shown in 2.3.

However, another issue to be mentioned, not directly connected with the TR 365 itself, is the fact that the profile method of surface topography measurement does not give complex information about surface texture, as the properties of non-master specimen differ a lot, depending on a chosen profile. So we cannot exclude the possibility that performing similar investigation for 3D (surface) parameters would result in obtaining closer values with both devices, as the consequences of measuring different profiles and non-homogeneity of surface would be severely limited.

To sum up, not only is there a problem with defining proper criteria of comparison and evaluation, but also a specimen choice may affect the results significantly. The recent release of Taylor Hobson shaft roughness standard may turn out to be a good solution to this problem.

All the difficulties outlined above show how difficult assessing credibility and repeatability of parameters measured with different instruments is. In consequence, user's consciousness and awareness are crucial for a reliable measurement of surface properties.

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