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COMPARISON OF CALIBRATION STANDARDS FOR STYLUS PROFILOMETERS

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Abstract: The surface texture measurement results obtained with use of stylus profilometers have to be both reliable and reproducible. One of the most important factors affecting the dependability and repeatability is the instrument gauge calibration. However, as there is a wide variety of the applicable calibration artefacts, both standardised and non-standardised, a choice of a proper one becomes difficult. As a contribution to the systematisation of the specified calibration standard applications, this paper describes the most popular calibration artefacts and outlines their advantages and drawbacks.

Keywords: stylus profilometer, calibration standard, gauge characteristics

1. INTRODUCTION

For the last few decades, surface roughness measurements have played a crucial role in predicting the performance of industrial objects, their wear and frictional properties. As a result, it has become vital to ensure that an extracted profile and calculated values of roughness parameters (i.e. *Ra*, *Rz*, *RSm*) are reliable and reproducible. In order to enforce this, proper calibration of a measuring instrument gauge is of immense importance. Also, a selection of calibration standard plays a key role in achieving adequate credibility of surface texture properties assessment, as the measurement results obtained with the non-calibrated or improperly calibrated equipment may cause reaching not only misleading, but even erroneous, conclusions.

However, as there is a wide variety of both standardised [1] and non-standardised [2, 3] calibration artefacts, and there is no information concerning their impact on the calibration uncertainty, a choice of an appropriate one has become extremely difficult. Before making a decision, numerous factors should be taken into consideration, i.e. measuring instrument type (stylus or non-contact one), its measuring range and resolution. So, the core objective of the paper is to compare the most widely used calibration artefacts, especially taking into account the possibilities and limitations of their applications for stylus instruments. Also, the repeatability of the calculated calibration coefficient values, while each of the mentioned standards being used, is compared. The instrument to be calibrated is the Form Talysurf PGI 830 by Taylor Hobson [4].

2. DEPTH MEASUREMENT STANDARD (TYPE A)

One of the artefacts devised to calibrate the measuring gauge of a stylus instrument is a depth measurement standard, which is recommended by ISO 5436-1:2000. There are two subtypes of this calibration specimen (fig. 1): A1 – deep grooves with flat bottoms (characterised by their depth *d* and width *w*), and A2 – deep grooves with rounded bottoms (characterised by their depth *d* and radius *r*). It is also worth mentioning that wide ridges with flat tops are interchangeable with the A1 type artefacts.

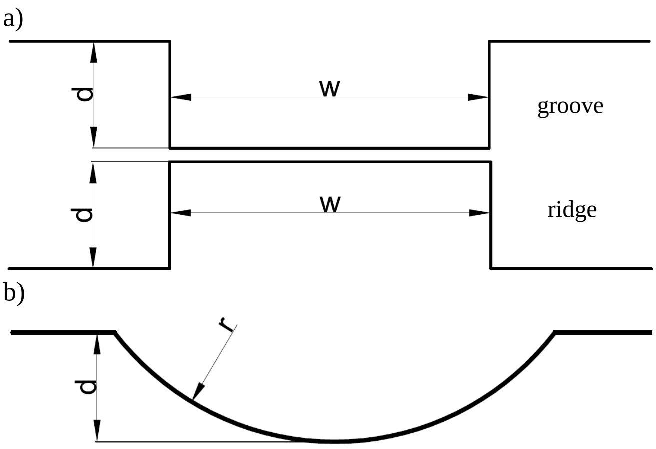

Fig. 1. Depth measurement standards: a) grooves with flat bottoms and ridges with flat tops, b) grooves with rounded bottoms

When the A1 type standard is used, the first step of calibration coefficient *Z* determination is fitting the equation:

$$Y = \alpha \times X + \beta + h \times \delta \qquad (1)$$

with unknowns: α, β, h, to the profile three times longer than the width of the groove using the least squares criterion. Y refers to the height of assessed profile at any position X. Also, the parts of the measured profile surrounding the groove corners should be ignored to avoid the influence of the rounding of these faults as it is shown in figure 2a. The variable δ should be set to either +1 (in regions I and II) or -1 (in region III) respectively. Then, the relation of the calculated depth of the groove equal to $2h$ to the nominal one *d* is estimated. The obtained value is the calibration coefficient Z.

Whereas the A2 type standard is used, the least square arc is fitted through the centre of the groove and the least square line referring to the upper level is fitted, too (fig. 2b). A least squares mean line representing the upper level is drawn over the groove. The calibration coefficient *Z* is estimated as the relation of the distance assessed from the line to the lowest point of the fitted arc and the nominal depth of a groove.

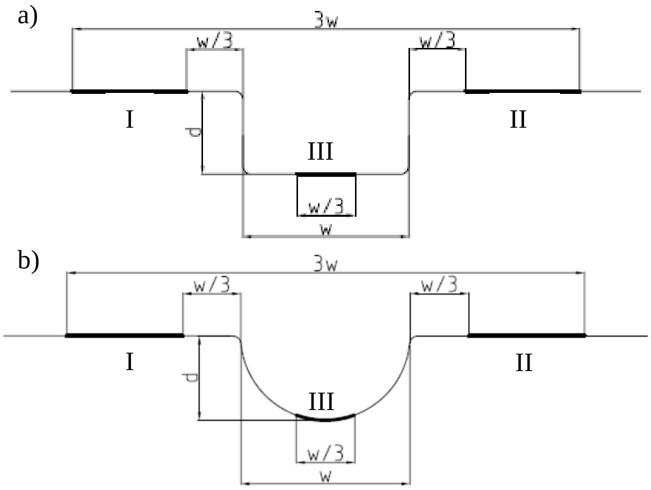

Fig. 2. Calibration coefficient evaluation
a) A1 type standard, b) A2 type standard

However, in order to limit the impact of the standard defects, a few (at least five) profiles, evenly distributed over the groove, should be measured according to the normative documents [1]. Another way to avoid this influence is measuring the standard with more than one groove on it [5], as it is shown in figure 3. This measurement procedure has been applied to assess the repeatability of the obtained calibration coefficient values. The results of the research are presented in figure 4.

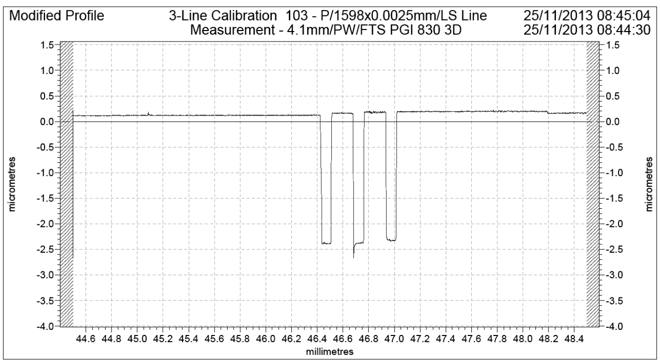

Fig. 3. The standard with three grooves measurement results

In spite of their simple construction, economical manufacturing and high precision, these standards are not free of drawbacks. The fundamental of them is the fact that it is impossible to reveal and compensate numerically the gauge non-linearity. It is an effect of calibrating the profilometer only for isolated points (reflecting the groove depth) within the measuring range. It makes the A type calibration standards non-applicable, when the performance of a wide range stylus profilometer gauge, such as one of the Form Talysurf PGI 830 used as a reference machine, is investigated.

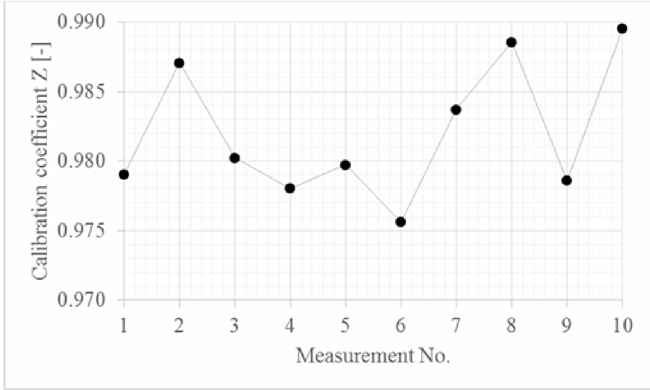

Fig. 4. The calibration coefficient value *Z* repeatability
(three-groove A1 type standard with a nominal depth *d* = 2.55 µm)

3. SPACING MEASUREMENT STANDARD (TYPE C)

Another calibration artefact, not only being the first, but also the most common, is the spacing measurement standard (type C) [1] (fig. 5), which is characterised by the averaged *Ra* or *RSm* parameter. *Ra* parameter refers to arithmetical mean of the absolute ordinate values within a sampling length. *RSm* is a mean value of the profile element widths within a sampling length.

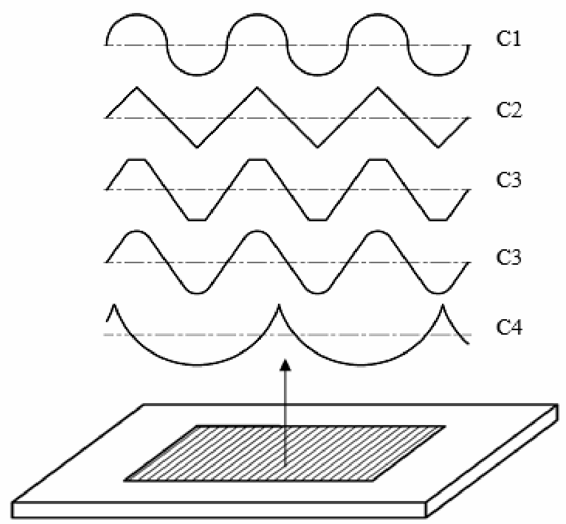

Fig.5. Spacing measurement standard [8]

The calibration coefficient *Z* is evaluated as a relation of the calculated and nominal roughness parameter values. Similarly to the A type standard, the impact of the artefact defects has to be minimised and the measurement has to be repeated at least 12 times [1], what makes the calibration procedure time-consuming. What is more, the calibration standard itself has some significant disadvantages, i.e. it is vulnerable to wear and damages. Also, the same as the depth standard it enables a user to calibrate instrument gauge only within small measurement range.

In order to evaluate the repeatability of the calibration coefficient estimation with a use of the C type standard, the measurement has been conducted 10 times. For each of the profiles *Ra* parameter has been calculated and divided by the nominal value. The results obtained this way are presented in figure 6.

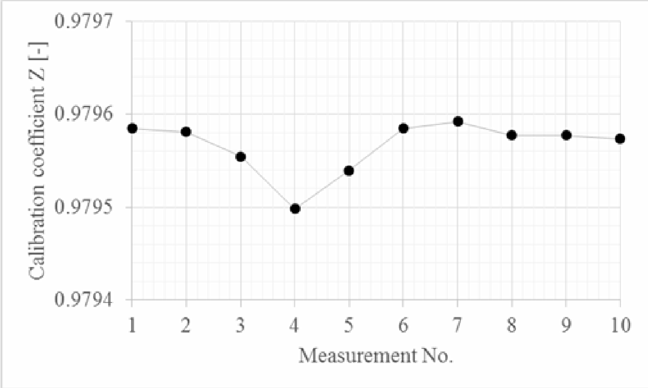

Fig.6. The calibration coefficient value *Z* repeatability (C2 type standard with a nominal *Ra* = 2.5 µm)

4. PRECISION HEMISPHERE STANDARD (TYPE E1)

The novel calibration method and standard had to be introduced due to the numerous profilometers with extraordinarily wide, exceeding 10 mm, gauge range coming onto the market. The solution devised by the metrology equipment manufacturers is founded upon using an optical quality, high precision hemisphere (fig. 7) [6, 7]. In spite of being perceived as worth popularising and standardised [1], there is nearly no information concerning the accuracy of the method available [8].

Fig.7. The precision hemisphere standard

According to the manufacturers' and standard recommendations, the first calibration step is determining the position of the hemisphere crest. However, the previous authors' research [8] has outlined, that even shifts of the determined and true hemisphere top exceeding 1 mm have a negligible impact on the calculated calibration coefficient value.

Then, the hemisphere profile data should be acquired symmetrically to the determined crest. Also, the length of the registered profile should be limited only by the instrument measuring range and the hemisphere geometry, as the stylus flanking on the surface of calibration standard is impermissible. Afterwards, the mean arc should be fitted to the obtained signal via a least squares criterion. What is more, the maximum hemisphere form deviations *Pt* should be calculated. The values acquired this way should be compared with the nominal ones. Then, the calibration coefficient *Z* should be determined, as it is equal to the relation of the fitted arc radius to the nominal arc radius.

Similarly to other calibration methods being described, the repeatability of the calibration coefficient *Z*, while the precision hemisphere being used, has been evaluated. In the Figures 8-9, there are both the obtained values of this coefficient and *Pt* parameter collated.

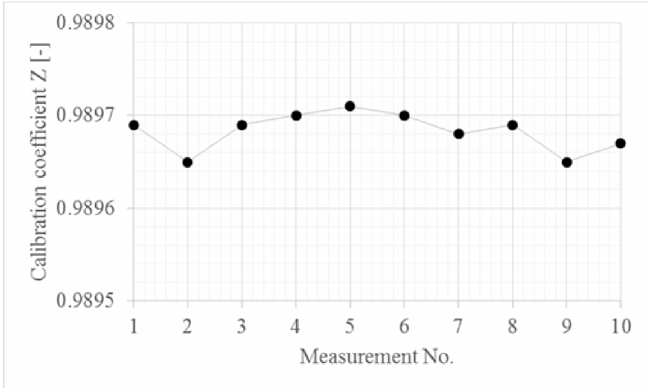

Fig.8. The repeatability of calibration coefficient *Z*

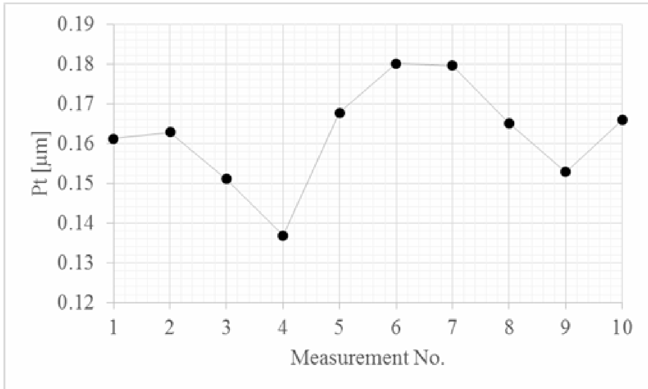

Fig. 9. The repeatability of *Pt* parameter

5. FINDINGS

The consistency in the calibration coefficient *Z* values obtained through use of the calibration standards mentioned above has been assessed. The differences between calibration results are presented in the box-whiskers chart in figure 10.

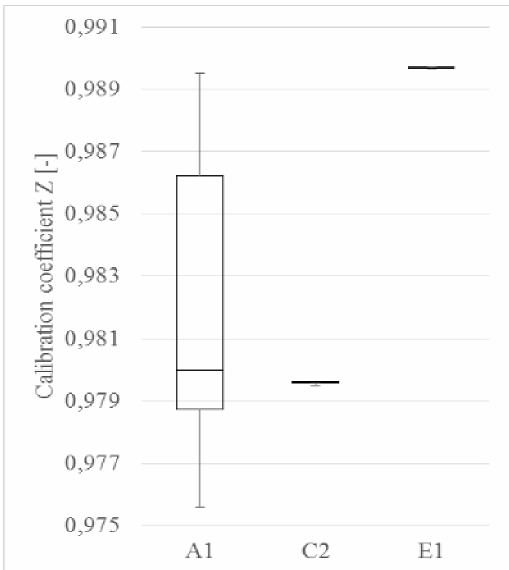

Fig. 10. The comparison of *Z* values obtained while various calibration standards being used

It can easily be observed that the repeatability of the calibration coefficient value when the A1 type calibration artefact is applied is significantly worse (the standard deviation being more than 100 times larger) than when other standards are used. However, this does not disqualify the calibration method performed through use of the deep groove standard, as the relative divergence of the acquired *Z* parameter values (referring to the mean value) does not exceed 1.5%. When other factors affecting the uncertainty of surface texture measurement are taken into consideration, this impact seems to be negligible.

Also, it has been outlined that the calibration coefficients given when A1 and C2 standards have been used are consistent with each other. On the other hand, a slight disparity between these calibration results and the ones obtained with a precision hemisphere standard may be observed. It may be a result of the different calibration artefacts' constructions and hence, a different part of the measuring range at which the instrument has been calibrated. However, this statistically significant diversity of the results also may be perceived as the one of no practical importance, as the relative difference between the calibration coefficient values does not exceed 1.5%, too.

6. CONCLUSION

The research has shown that the precision hemisphere standard may be an effective alternative to the standards traditionally used to calibrate the stylus profilometers gauges. It combines not only sufficient repeatability of the calibration performance, but also enables user to calibrate measuring machines of the extra-ordinarily wide measuring ranges, exceeding a few millimetres.

On the other hand, the hemisphere standard is one of the most expensive standards commercially available. The problem becomes even more significant, when the stylus flanking on the standard surface is considered, To avoid this, it may be necessary to equip the laboratory with a separate hemisphere standard for each type of measuring instrument.

All the matters mentioned above show how difficult it is to perform the calibration of a profilometer gauge properly. Not only is there a variety of standards to choose from differing in their metrological properties noticeably, but also a user has to take a hard look on the economic issues before making a decision which calibration method should be used.

7. REFERENCES

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PORÓWNANIE WZORCÓW UŻYWANYCH DO KALIBRACJI PROFILOMETRÓW STYKOWYCH

Streszczenie: Profile zaobserwowane i wartości parametrów, służące do oceny chropowatości powierzchni, uzyskane przy użyciu profilometrów stykowych muszą być wiarygodne i odtwarzalne. Jednym z najważniejszych czynników, decydujących czy te warunki są spełnione, jest przeprowadzenie wzorcowania głowicy pomiarowej przyrządu ze szczególnym uwzględnieniem doboru odpowiedniego wzorca. Jednak, ze względu na mnogość dostępnych wzorców kalibracyjnych, zarówno znormalizowanych, jak i nieopisanych w dokumentach normalizacyjnych, wybór właściwego stanowi trudne wyzwanie nawet dla doświadczonego metrologa. Wzorce te różnią się nie tylko strukturą geometryczną powierzchni, ale też kształtem, wymiarami, materiałem, z którego są wykonane czy ceną. W związku z tym, usystematyzowanie wiedzy dotyczącej wzorców kalibracyjnych, ich właściwości oraz potencjalnych zastosowań wydaje się niezbędne. W artykule porównano najbardziej rozpowszechnione spośród wzorców służących do wzorcowania głowic pomiarowych profilometrów stykowych. Poza przedstawieniem najważniejszych zalet i wad tych wzorców, dokonano też oceny powtarzalności wyznaczanych przy ich użyciu wartości współczynników wzmocnienia.

Słowa kluczowe: profilometr stykowy, wzorzec kalibracyjny, charakterystyka głowicy pomiarowej.