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The impact of the colour of the surface on the results of measurements taken with the use of a triangular laser head

Streszczenie. *W artykule zaprezentowano rezultaty badań dokumentujące wpływ koloru powierzchni odniesienia na wyniki pomiarów realizowanych z zastosowaniem laserowej głowicy triangulacyjnej. Różne kolory próbek zostały uzyskane poprzez naniesienie warstw ochronnych lub dekoracyjnych za pomocą metod PVD. Zastosowanie warstw $Al_{0,7}Cr_{0,15}Ti_{0,15}N$, CrN, TiN, a-C:H:N, oraz Al umożliwiło uzyskanie pięciokolorowej palety 10 próbek, w której każdy kolor jest nałożony na dwie powierzchnie o rożnych wartościach chropowatości (0.32 µm oraz 0.63 µm).*

Abstract. *The article presents the results of tests investigating the influence of the colour of the surface on the outcomes of measurements taken with the use of a triangular laser head. The differentiation of colours of the test samples was executed by the deposition of a protective-decorative layer in the PVD process. The application of the following layers: $Al_{0,7}Cr_{0,15}Ti_{0,15}N$, CrN, TiN, a-C:H:N, and Al resulted in the procurement of a palette of five colours for 10 samples, in which each colour was deposited onto two surfaces with different roughness value (0.32 µm and 0.63 µm).* ***(Wpływ koloru powierzchni na wyniki pomiarów przeprowadzonych za pomocą głowicy triangulacyjnej)***

Keywords: laser triangulation, colour of the surface, measurement of distance, dispersion of indications
Słowa kluczowe: triangulacja laserowa, kolor powierzchni, pomiar odległości, rozrzut wskazań

Introduction

Laser triangulation is a measurement technique frequently applied in the noncontact determination of distance [1, 2, 3, 4]. Due to the high frequency of measurement, it can be used for the investigation of elements that are in motion [5]. The method is however sensitive to changes in test conditions, which result from differing roughness, texture, shine and colour of the analysed surfaces [6, 7]. The objective of undertaken investigations was to determine the impact the colour and the roughness of the surface have on the repeatability of measurements taken with the use of a triangular head. The head used in investigations is applied in the measurement system of the penetrometer for the determination of substance properties, which are measured based on the dip of a plunger, at the end of which a measuring cone is placed. In the analysed solution, the dip is measured with the use of a triangular head which projects a laser spot onto the surface of the head of the penetration plunger. The results of investigations are used for the determination of structural parameters of the plunger in form of the colour and the roughness, for which laser measurement taken with the triangular head in question is characterised by the smallest dispersion of measurement deviations.

Triangulation is a method for measuring the distance with use of optical (laser) distance meter. Laser is a source of light that goes through optical path falls on the surface of the measured object. The image constructed at the surface from the reflected light beam (point, line) is recorded by a CCD camera, which is located in a known position from the laser. The variation of the distance between the source (laser) and the surface of the object influences the angle at which the light spot is observed at that surface (Fig. 1). The laser diode emits the light beam, which reproduction as a spot at the tested object is read as a projection on the optoelectronic CCD circuit. The receiver is located from the transmitter by constant distance away name base (b) and tilted by angle α. The light beam reflected from the object in the distance r falls on the CCD detection behind the receiver's lenses. By knowing the focal length of lenses and the location of falling light beam on the detector (dx) we can calculate the distance from the lenses.

Best accuracy is achieved when the light beam is projected along the normal to the measured surface. The angle between the light beam and a normal to the surface effects the accuracy of the measurement (increase of the deviation). In laser triangulation measurements, the image on the PSD (position sensitive detector) of the object spot is one of the main factors that influences the measuring accuracy. So it is important to study the size and the light power density distribution of the image spot [8, 9]. So far, in most research work, the size of the object spot has not been considered and has been regarded as an ideal point. However, the size of the object spot cannot be neglected in many conditions.

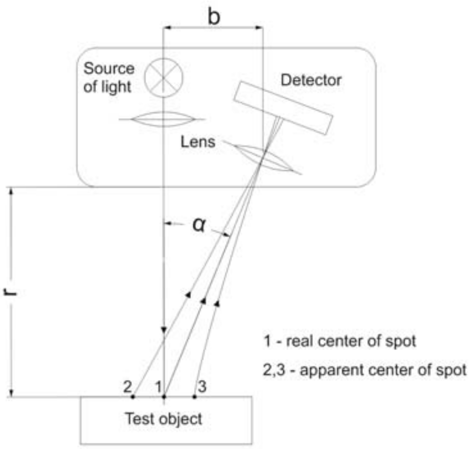

Fig.1. Measurement by a laser triangulation sensor

The colour, the roughness of the surface on which the light beam is projected influence its shape and reflection, which in turn influences the detection of the centre of the spot (e.g. the borders of different colours on the surface the edge of the object) [10,11].

Test objects

Two kinds of flat surfaces made of stainless steel with the roughness of 0.63 µm and the texture of 0.32 µm, that had previously been subject to electrical discharge machining were tested. In order to obtain the proper colour, the samples were then subject to PVD processes, with the use of which the coating from the gaseous phase was deposited on the sample [12]. In the PVD process, five coatings of different colour were deposited. As a result, a palette of five colours which were deposited on the surface with the roughness of 0.63 µm and 0.32 µm was obtained. The 5 deposited layers included the following:

- $Al_{0,7}Cr_{0,15}Ti_{0,15}N$ (graphite grey),
- CrN (light graphite grey) [13],
- a-C:H:N (dark graphite grey) [14],
- TiN (gold),
- Al (silver).

Colours varying from very dark to very bright shades were used. They are characterised by different light wave absorption, which enables a review of the extent to which the colour of the surface influences the operation of the measurement system in the triangular laser head (Fig. 2).


a) Graphite grey


b) Light graphite grey


c) Dark graphite grey


d) Gold


e) Silver

Fig.2. Test samples: a) aluminium, chromium and titanium nitride $Al_{0,7}Cr_{0,15}Ti_{0,15}N$, b) chromium nitride CrN, c) diamond-like surface a-C:H:N, d) titanium nitride TiN, e) aluminium Al

Each test sample was mounted onto the head of the plunger (Fig. 3) imitating the type of the plunger used in the penetrometer fit to cooperate with the measurement stand.

Fig.3. Plunger

The tip of the plunger is equipped with a ball, which ensures the point contact with the gauge block.

Test stand

The tests were carried out on the test stand that is a physical model of a laser penetrometer in which the triangular head is mounted perpendicularly to the tested surface with the use of a stiff support (Fig. 4). The user panel enabled automatic execution of the process and allowed measurement data to be recorded in a digital form.

The measurements were taken with the use of a triangular laser head by PEPPER+FUCHS, whose working range is 100 mm, the minimum measurement distance - 30 mm, and the measurement range - 70 mm. The head’s resolution was 0.1% of the measurement range at its 0.25% linearity.

The dimensions of the projected laser spot were 1.5 mm x 3 mm at the beginning of the measurement range, and 1.5 mm x 3.25 at its end. The measurement distance was adjusted with the use of gauge blocks (class 1), which formed the support for the plunger located in the grip.


a)


b)


c)


d)

Fig.4. Test stand: a) configuration of the plunger, laser head and gauge blocks, b) view of the laser spot on the CrN surface, c) view of the laser spot on TiN surface, d) view of the laser spot on Al surface

Methodology of research

The test were carried out for 20 samples, and for each of them a set of differently coloured coatings deposited on a suitable surface was represented in form of two samples produced with the use of an identical technology. The tests were conducted in the shift range of 1-60 mm characterised by a changeable stroke, which amounted to 1 mm for the 1-5 mm shift, and 5mm for the 5-60 mm shift.

The measurements were taken for 16 measurement distances determined with the use of gauge blocks. For each of the samples, 10 measurements in the same measurement distance were taken. In order to avoid any errors, the sample was rotated at the angle of 6° (around its vertical axis) prior to the measurements.

There were 3200 measurements taken in total.

Test results

Based on the recorded results, the measurement deviations were estimated for each of the measurements taken. The term “measurement deviation” was used with reference to the difference between the measured value and the real value of the measured quantity. The measurement results in question are presented in the graphs of measurement deviations estimated for every measurement distance taken into consideration. In order to improve their readability, the graphs show only border lines of top and bottom deviations and a line representing the course of average deviation value changeability estimated based on 10 measurements taken for each measurement distance (Fig. 5).

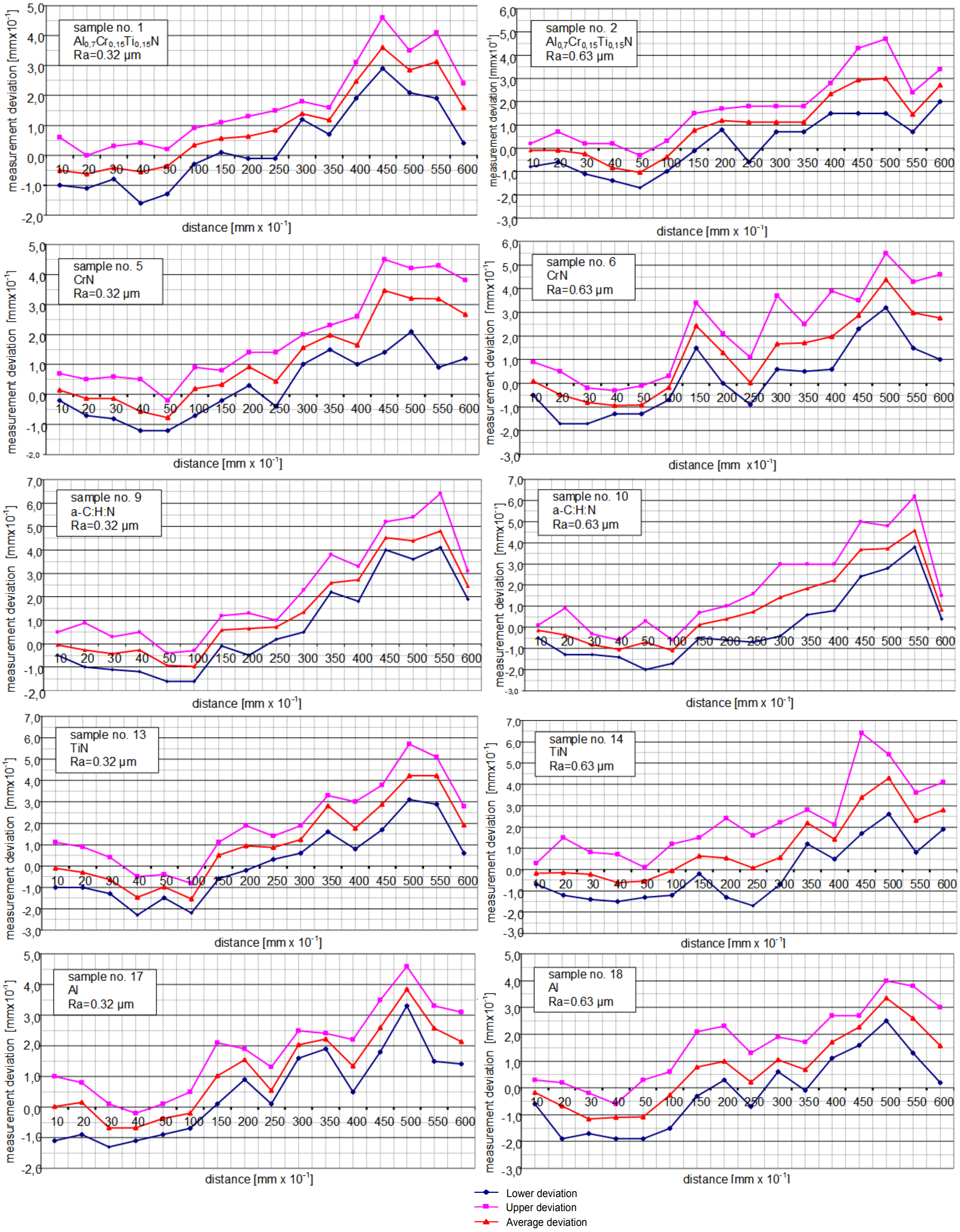

Fig. 5. Measurement deviation dispersion for selected samples

Analysis of the results

For each test sample an average dispersion of deviations from the measurements taken for all 16 measurement distances was estimated (Fig. 6).

Table 1 shows that standard deviation values are in the range from 0.16 to 1.61 mm.

The lowest value of dispersion, calculated as the mean of all measurements taken for a given sample, was observed for the surface with roughness Ra = 0.32 μm onto which a diamond-like layer (a-C:H:N) had been deposited (sample no. 9 and 11). For this sample total sum of standard deviations (for all distances) is the smallest, values are in the range from 0,22 to 0,88 mm

The changeability of dispersion in the entire measurement range was determined by the estimated changeability coefficient V= 30% (Fig. 7).

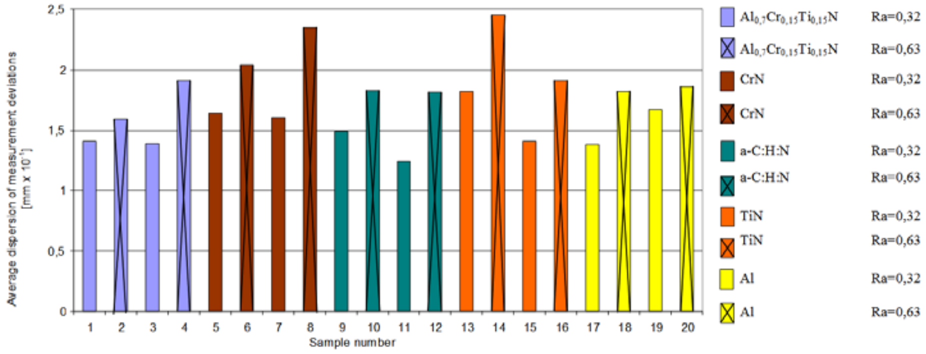

Fig.6. Average dispersion of measurement deviations of tested samples

Table 1. Standard deviation results at different distance - sample number relations

		Sample number																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Distance [mmx10^-1]	**10**	0,47	0,30	0,16	0,23	0,26	0,49	0,65	0,66	0,35	0,20	0,34	0,27	0,71	0,31	0,42	0,24	0,69	0,35	0,40	0,56
	20	0,35	0,48	0,44	0,51	0,31	0,74	0,45	0,47	0,50	0,70	0,46	0,44	0,58	0,80	0,62	0,86	0,54	0,65	0,25	0,53
	30	0,36	0,39	0,36	0,40	0,41	0,48	0,34	0,54	0,48	0,31	0,56	0,46	0,54	0,77	0,37	0,38	0,44	0,44	0,42	0,57
	40	0,53	0,55	0,33	0,63	0,57	0,33	0,38	0,28	0,56	0,32	0,42	0,57	0,55	0,72	0,36	0,43	0,28	0,40	0,64	0,43
	50	0,44	0,47	0,66	0,41	0,33	0,38	0,52	0,71	0,39	0,84	0,42	0,66	0,35	0,42	0,43	0,55	0,29	0,63	0,66	0,48
	100	0,33	0,38	0,41	0,21	0,51	0,32	0,50	0,58	0,41	0,36	0,24	0,82	0,44	0,74	0,55	0,93	0,39	0,75	0,45	0,46
	150	0,32	0,42	0,43	0,39	0,38	0,67	0,40	0,67	0,35	0,50	0,49	0,61	0,50	0,51	0,63	0,44	0,56	0,84	0,34	0,68
	200	0,49	0,28	0,49	0,66	0,30	0,64	0,31	0,64	0,50	0,61	0,22	0,62	0,66	0,99	0,24	0,77	0,31	0,72	0,73	0,76
	250	0,59	0,68	0,54	0,59	0,64	0,71	0,54	0,63	0,26	0,84	0,33	0,42	0,34	0,98	0,68	0,32	0,34	0,67	0,66	0,78
	300	0,21	0,34	0,34	1,02	0,32	1,02	0,56	1,23	0,61	1,18	0,42	0,53	0,43	0,97	0,16	0,38	0,28	0,44	0,45	0,60
	350	0,34	0,42	0,48	0,59	0,26	0,64	0,25	0,68	0,48	0,88	0,25	0,63	0,47	0,50	0,31	0,99	0,20	0,68	0,39	0,62
	400	0,40	0,43	0,38	1,20	0,49	1,14	0,60	0,59	0,47	0,76	0,25	0,62	0,71	0,58	0,59	0,82	0,47	0,59	0,23	0,39
	450	0,61	0,85	0,25	0,88	1,00	0,43	0,96	0,60	0,39	0,82	0,29	0,52	0,61	1,41	0,36	0,71	0,54	0,37	0,43	0,57
	500	0,47	1,07	0,62	0,96	0,66	0,71	0,73	0,94	0,57	0,56	0,45	0,87	0,69	0,94	0,48	0,71	0,41	0,48	0,47	0,45
	550	0,68	0,69	0,70	0,81	1,04	0,75	0,48	1,61	0,85	0,65	0,88	0,55	0,84	0,84	0,62	0,76	0,47	0,80	1,04	0,73
	600	0,60	0,49	0,60	0,96	0,70	1,03	0,72	0,72	0,40	0,36	0,44	0,92	0,70	0,80	0,41	0,93	0,57	1,04	0,85	1,03
	Σ	7,19	8,24	7,19	10,45	8,18	10,48	8,39	11,55	7,57	9,89	6,46	9,51	9,12	12,28	7,23	10,22	6,78	9,85	8,41	9,64

The greatest dispersion, almost twice as large as in the aforementioned case, can be observed for a sample with roughness Ra = 0.63 µm, which is covered by a titanium nitride (TiN) layer. The changeability of dispersion in the entire measurement range is determined by the changeability coefficient V= 29% (Fig. 8). For this sample standard deviation values are in the range from 0,31 to 1,41 mm.

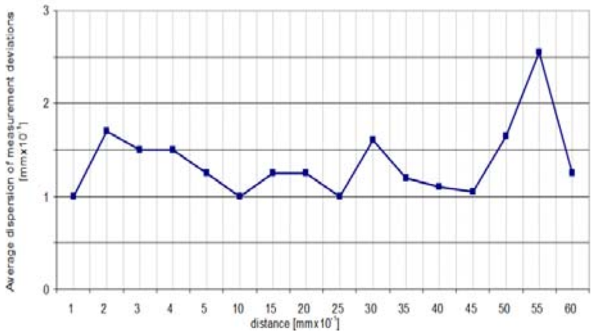

Fig. 7. Changeability of the average dispersion of measurement deviations in the entire working range of the triangular laser head for a sample covered with a diamond-like layer a-C:H:N with roughness Ra = 0.32 µm

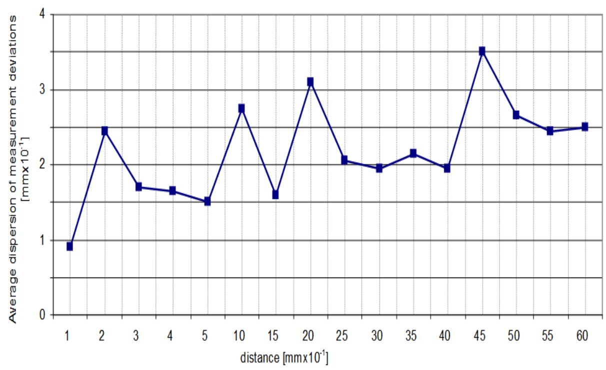

Fig. 8. Changeability of the average dispersion of measurement deviations in the entire working range of the triangular laser head for a sample covered with a titanium nitride (TiN) layer with roughness Ra = 0.63 µm

Summary

Based on the tests and analyses conducted, it can be stated that the colour of the surface and its roughness significantly influence the accuracy of measurements taken with the use of a triangular laser head. The greatest dispersion was recorded for samples with the surface roughness of 0.63 μm, whereas for surfaces with the same colour but the surface roughness of 0.32 μm, the dispersion was much lower. Dark surfaces introduce fewer disturbances, which results in lower dispersion of measurement deviations.

The best measurement values defined based on the average dispersion of measurement deviations, were recorded for the surface with 0.32 μm roughness on which the a-C:H:N coating was deposited. Such type of a surface should be applied as a reference surface for the penetration plunger onto which the laser spot is projected in the measurement system of the penetrometer for substance property tests.

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