TERRESTRIAL LASER SYSTEM TESTING USING REFERENCE BODIES

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Abstract: The paper deals with terrestrial laser system (TLS) testing based on scanning of reference bodies which geometry is know and which represent the standard (etalon) for the models created from scanned data. Two reference bodies of different shape – blocks and cylinders, are designed and made from material, which is temperature stabile and durable (resistant) against the mechanical damage. The surface of the bodies is sprayed by mat grey colour, to minimize the light reflections on their surface. The geometry of the bodies is controlled (given) by photogrammetric method – based on convergent projection. The accuracy of the model determination is given by the standard deviation of the created models or their parts - plane 0,045 mm and cylinder 0,035 mm. The testing procedure consists from parts which aim is to determine the influence of the distance between the TLS and the scanned structure, the different orientation of the scanned structures according to the TLS, different position of the scanned structure in the TLS measuring range, to the quality of scanned data and created models. The models of reference bodies are created by regression surfaces. The geometrical parameters of models – planarity, cylinder form, parallelism, co-linearism, etc., are calculated from the models. Comparison (matching) of the given parameters and parameters calculated from models are made by different relative position and orientation of the TLS and the scanned structure. Results are presented. According the test results the information is given about the stability of the TLS. Characteristics and critical positions in the measuring range of the tested TLS are given.

1. Introduction

One of the most important criteria according to the application of laser scanning technology is the scanning accuracy or the accuracy of the determined points. The producers often describe the system quality by the scalar value, which is not enough specified and clear. It is also difficult to compare the different TLS based on the characteristics, which are given by the producers. The users show the positive or the negative characteristics of the TLS by their practical usage, only. There are a number of projects started with the aim testing the TLS and determinate the real property and parameters of the TLS. The first test was made in 2000 and new and new procedures are presented all the times.

To this time is not know the complex technology for TLS testing, which would be give the users objective information about the sufficiency (ability) of the tested TLS to register the real scene and objects. It is evident, that the professionals appeal for the more detailed information about the measured data and model quality given by TLS. Exactly this fact started the design of concepts for new TLS testing, using real objects. Realized tests and obtained practical skills should be helpful to design of new universal test procedures, in the future.

2. Test principle

The principle of the test is the scanning of objective reality. The scanned scene is presented by real objects (structures), which are in different positions and distances to the tested TLS, are scanned with different part of the field of view of the TLS. The test simulate the real scene by the testing structures (bodies) described by know geometry and stabile shape. Test measurements are designed, to cover characteristics of the scanned reality.

The data processing includes model creation (model of testing bodies) and measurement of their geometry characteristics. The quality of the model covered by the tested TLS will be defined by the comparison of measured and know model parameters.

3. Reference bodies

The reference bodies represents the know geometry of the scanned scene, the etalon. This enables the comparison of characteristics covered by the point cloud of the tested TLS with the know characteristics, e. g. differences to the plane or cylindrical surface, dimensions, angle differences between body axes, etc. The design of the reference bodies (RB) accepts the characteristics of the know TLS´s, the test measurement technology and their application in different conditions and time. The dimension and weight of RB are limited by the possibility of their transportation, accurate production (preparation) and handiness. RB´s are given by own shape, dimensions, material, colour, production and their accuracy.

3.1. The shape of RB´s

The recognised geometric parameters will be derived from the modelled planes of the RB´s. The possibility of the subjective impact to the model building will be minimised using simple geometrical shapes, which have the simple mathematical formulation and enable the smart and responsible data analysis. Another side, to have the possibility of the verification of different geometrical characteristics, the designed RB´s were built from simply geometric bodies.

a) reference blocks

b) reference cylinders

Fig. 1 Designed RB´s

There are designed and made two RB´s for the test (Fig. 1). The first RB is built from two blocks of different dimension and positioned centric over there. The second one consists from two cylinders with common axes, but different diameters [3].

3.2. The dimension of RB´s

Dimension of the RB´s was designed to achieve the enough number of measured points, which are needed for responsible modelling of their surfaces. Another side was their dimension limited by the required accuracy of production and the handiness of the RB´s. According to these requirements were the dimensions of the RB´s defined:

- 450 mm × 450 mm × 250 mm, resp. 150 mm × 150 mm × 250 mm for the reference blocks,
- the diameter 400 mm and 180 mm and high of 250 mm for the reference cylinders.

3.3. Material, colour, preparation and accuracy of RB´s

According to the requirement of the simply manipulation with RB´s and their small weight are these designed as a tubular body. The RB´s are made from glass textiles, which is slim and slight material. This material fulfil the temperature requirements and the structure build with them is mechanical stabile and hard. The RB´s are sprayed with grey colour with very good reflection parameters from the point of view the TLS used wave lengths [1]. There are accepted the requirements according to the maintenance and the cleaning of the RB´s, too.

The accuracy of the RB production is defined according to the accuracy of the modelled surface, which is given by TLS producers with value between 3-10 mm. Because the RB´s define the etalon for the test, would be these made with accuracy of 10 times better, mainly in the surface quality (planarity or cylindricality).

The dimension and the shape of the RB´s were controlled by photogrammetric method with images in general position, made by Olympus C-8080WZ digital camera. The distance between the digital camera and the RB´s was 1,5 m. The observed points on the surface of the RB´s are signed by special signals made from white coloured sheet. The density of measured points is given by the raster of ca 18 mm x 18 mm on the surface of the RB´s. Resulting this are on the reference blocks 2510 signals used and on the reference cylinders 2319 signals. The accuracy of the photogrametric determined co-ordinates of these points is given by 0,03 mm on the blocks and 0,06 mm on the cylinders [3].

Using the points determined by photogrammteric method was the 3D model of RB´s created, by Cyclone 5.3. The residuals of the measured points according to the adjusted surfaces of RB´s could be described by their standard deviation, which achieve the value of 0,05 mm. Also the high quality of the RB´s was declared this way.

The photogramteric determined 3D models of the RB´s, will be used as the nominal 3D models for the test. The geometric parameters of these models were used as the nominal parameters of RB´s. With these parameters will be compared the model parameters achieved (obtained) by the TLS during their testing.

3.4. The fixation of RB´s in the space

During the test the RB´s should be placed in different positions and should have the different orientation in the space. To minimise the generation of virtual points, the RB´s should be not placed on another surface, but in a "free space" of the laboratory [2]. For the fixation of the RB´s in a space in different positions was made the special holder, which enable their rotation in both the horizontal and the vertical plane (Fig. 1). The holder don´t enables the rotation of the RB´s according to their centre because the very complicate and big fixation element should be used on the holders. In this case could be not scanned the whole surface (part of RB whit the fixations element) and the effect of bad edge detection will be proved on these RB part.

The rotations of the RB´s in space are specified as:

- turning – for the rotation in horizontal plane,
- inclination – for the rotation in vertical plane,
- rotation – for the rotation according the body axis.

The orientation of the RB in space is defined by measurement of three angles with standard deviation of 2°.

4. Test realisation

Test of TLS are realised by two TLS, the camera view Leica HDS 2500 and the panorama view Callidus CP 3200 (Figure 2). The tests are made in the Laboratory of the Department of Surveying of the SUT Bratislava. The Leica HDS 2500 was used in the frame of international co-operation and research with the Department of Surveying of the TU Munich. The test measurement made by the CP3200 was supported by the GEOSPOL Košice (Slovakia). The producers describe the TLS by different parameters (Table 1), which don´t enable the direct comparison of the tested TLS.

Leica HDS 2500

Callidus CP 3200

Fig. 2 Used TLS

Tab. 1 Parameters of the used TLS

Product	**Leica HDS 2500**	**CALLIDUS CP 3200**
Measured point accuracy		
Position	6 mm@1,5 m - 50 m	5 mm
Distance	4 mm	
Angle	0,003°	
horizontal		0,005°
vertical		0,009°
Modeled surface accuracy	2 mm	2,5 mm
Measurment range	do 100 m	
recommended	1,5 m - 50 m	32 m
Field of view		
vertical	40°	40°-180°
horizontal	40°	0°-360°

The aim of the realised tests is to determinate the impact of the distance and the position (orientation) of the scanned object to the model accuracy. The realisation of scans with RB´s in different position according to the filed of view of the TLS give information about the stability of TLS parameters and the homogeneity of the TLS model. The absolute 3D position of measured (scanned) points will be controlled by autonomous geodetic method. To obtain all these information were following test developed and realised:

- POSITION – the RB´s are in different positions to the tested TLS,
- DISTANCE – the RB´s are in different distances to the tested TLS,
- HOMOGENEITY – the RB´s are scanned in different part of the field of view of the tested TLS,
- MODEL POINTS – there are compared the direct measured points given by TLS and total station.

Tests are realised under laboratory conditions, with constant illumination and temperature. The background of the RB´s is chosen of black colour to minimize the reflections and generation of virtual points. Density of scanned points is different according to the tested TLS and the used tests. The density of 1,2 mm was used for the HOMOGENEITY and DISTANCE test and 2,4 mm for the POSITION test, which are made by the HDS 2500. For the all test are the step of 0,25° in vertical and 0,0625° in horizontal direction used by the CP3200.

The data processing of the first three tests could be described by following steps:

- modelling of the RB´s – using point cloud determined by TLS,
- measurement of model parameters – dimension, parallelism and perpendicularity of the model surfaces, standard deviation of measured points to the adjusted plane (surface), diameter and high of the model cylinders.
- comparison of nominal and measured model parameters,
- numerical and graphic analysis of differences.

Data processing of the MODEL POINTS test are different and include:

- determination of control point co-ordinates by total station,
- transformation parameter calculation and 3D transformation of model points,
- comparison of model point co-ordinates (transformed) and co-ordinates determined by the total station,
- data analysis, accuracy determination of the 3D co-ordinates given by TLS.

Resulting the provided tests and realised data analysis was the optimal set of tests defined. Realisation these tests and their analysis enable the sufficient (adequate) valuation of the tested TLS. The aim of this optimisation is to minimise the time and measurements needed for testing the TLS by retaining the possibility of the adequate data analysis, which result to the adequate description of TLS parameters and quality.

4.1. The POSITION test

During this test the distance between the TLS and the RB´s is constant. The orientation of the RB´s in space is changed with their turning, inclination and rotation by 15° step. The TLS head and the RB´s are in the same level during the test, the head of the camera type TLS was in horizontal position.

There were made scans of 147 positions of the reference blocks and 49 positions of the reference cylinders using the HDS 2500 and 98 positions of blocks and 49 positions of the cylinders using the CP 3200. The distance between the TLS and the scanned RB´s was 10 m for the HDS 2500 and 3 m for the CP 3200.

In different positions of RB´s are evaluated the residuals of measurement points to the adjusted planes (surfaces), the dimensions of RB´s, parallelism of model planes of the RB´s, the alignment of RB axis, the angle of model planes (Table 2 and 3).

Tab. 2 Differences between the model and nominal parameters – reference blocks (HDS 2500, CP 3200)

Differences to the		HDS 2500				CP 3200			
		min Δ	max Δ	mid.val. of Δ	range of Δ	min Δ	max Δ	mid.val. of Δ	range of Δ
adjusted surface σ_{rez}	[mm]	0,27	3,70	1,36	3,43	0,58	9,33	2,28	8,75
min distance	[mm]	-3,30	1,57	-0,15	4,87	-10,24	9,09	0,47	19,33
parallelism	[´]	-36,7	7,8	-5,7	44,5	-488,7	9,3	-79,5	498,0
nominal angle values	[´]	-41,1	50,2	1,7	91,3	-441,5	470,0	0,6	911,5

Tab. 3 Differences between the model and nominal parameters – reference cylinders (HDS 2500, CP 3200)

Differences to the		HDS 2500				CP 3200			
		min Δ	max Δ	mid.val. of Δ	range of Δ	min Δ	max Δ	mid.val. of Δ	range of Δ
the adjusted surface σ_{rez}	[mm]	0,53	2,96	2,19	2,43	1,05	3,50	2,48	2,45
nominal diameter	[mm]	-0,17	6,86	4,17	7,03	-48,69	10,86	-14,95	59,55
nominal high	[mm]	0,11	0,69	0,42	0,58	-0,79	3,72	1,36	4,51
axis alignment	[´]	-3,2	33,3	5,0	36,5	-43,6	121,1	18,0	164,7

The angle differences are given by angle minutes. Non parallelism of the modelled planes given by 10´made on 0,1 m long distance (RB edge) the cross (lateral) difference of 0,29 mm.

According to the analysis of **RB surfaces** scanned from different positions (by the HDS 2500 and the CP 3200), the following conclusions were made:

- With the increasing angle of incidence (horizontal and vertical) of the TLS laser beam is smaller the number of measured points on the scanned surface and the residuals from the adjusted surface are smaller. Similar this, with the higher angle of incidence, the dispersion of the measured points around the scanned surface will be smaller.
- The residuals of the measured points to the adjusted surfaces with the same angle of incidence (the orientation of the surface in the space is the same) are similar.

Following the analysis of differences between the **modelled and the nominal parameters (dimensions) of the tested RB´s** could be conclude, the differences are smaller, when the surfaces used for the calculation of the parameter are scanned by the same conditions (the same scanning density, the same orientation in space, etc.). This is thru in 95% of parameters calculated from the HDS 2500 measurements and 78% in the case of CP 3200. In more than 78% cases (in 80% cases measured by the HDS 2500 and 78% given by the CP 3200) of **diameter determination of the reference cylinders** was recognise, the big angle of incidence to the cylinder surface (cylinder jacket) results the minimal differences between the modelled and the nominal diameter of the cylinder.

Resulting to the analysis of differences between the determined and nominal **high of the reference cylinders** were achieved the different conclusions in the case of HDS 2500 and the CP 3200. For the HDS 2500 could be concluded, the big angle of incidence results the small differences from the nominal highs (83% of measurements). The differences calculated from the CP 3200 measurements are higher and have the higher oscillation amplitude for the different RB position. Dispersion of the measured points to the adjusted surface is similar for the both TLS, but smaller number of points is used for modelling of the RB surface, in the case of CP 3200.

The angle differences of parallel model planes show any relation. The **axis alignment of the reference cylinders** given by HDS 2500 can be described by values between -3,2´and +10,2´, which are unremarkable values. In cases, when the angle of incidence to the cylinder surface (jacket) is big, are achieved values until 36,5´. The alignment of cylinder axis given by the CP 3200 has unreasonable differences, with oscillations between the neighbour positions of the reference cylinders.

The 86% of differences between the **nominal and given angle values** (angle of RB planes) determined by HDS 2500 are from the range -10´ to +10´. The 81% of angle differences given by CP 3200 are from the range -100´ to +100´.

4.2. The DISTANCE test

During this test the distance between the TLS (HDS 2500) and the RB´s was changed from 10 m to 60 m by 10 m step. For this test two positions (orientation) of the RB´s were chosen, which gives the best results during the POSITION test. There are given by:

- 20° turning, 45° inclination and 0° rotation and 45° turning, 45° inclination and 0° rotation of the reference blocks,
- 90° turning, 45° inclination and 45° turning, 45° inclination of the reference cylinders.

For the CP 3200 was the range of 2 m to 10 m prepared with step of 2 m.

The main requirement of this test is to retain the geometric parameters of the RB models according to the changeable distance of the scanned object and the TLS. Achieved results are presented in table 4 and 5.

Tab. 4 Differences between the model and nominal parameters – reference blocks (HDS 2500, CP 3200)

Differences to the		HDS 2500				CP 3200			
		min Δ	max Δ	mid.val. of Δ	range of Δ	min Δ	max Δ	mid.val. of Δ	range of Δ
adjusted surface σ_{rez}	[mm]	0,61	2,99	1,74	2,38	0,00	6,75	2,74	6,75
nominal dimension	[mm]	-3,14	1,68	-0,28	4,82	-6,28	9,47	0,74	15,75
parallelism	[´]	-40,5	4,4	-6,6	44,9	-340,1	-14,5	-129,5	325,6
nominal angle	[´]	-43,0	49,4	-1,0	92,4	-487,1	186,2	-24,8	673,3

Tab. 5 Differences between the model and nominal parameters – reference cylinders (HDS 2500, CP 3200)

Differences to the		HDS 2500				CP 3200			
		min Δ	max Δ	mid.val. of Δ	range of Δ	min Δ	max Δ	mid.val. of Δ	range of Δ
adjusted surface σ_{rez}	[mm]	1,54	2,23	1,89	0,69	2,07	3,34	2,54	1,27
nominal diameter	[mm]	0,44	6,80	2,97	6,36	-37,75	12,91	-8,06	50,66
nominal high	[mm]	0,59	0,91	0,61	0,32	0,76	4,75	2,36	3,99
axis alignment	[´]	-1,3	9,8	2,4	11,1	-60,1	65,9	5,9	126,0

Differences between the model parameters and their nominal values have variable characteristic, increasing according to the increased distance. The increasing character of differences was registered for both the reference blocks and the reference cylinders. In the case of reference blocks:

- are higher the differences and their standard deviation calculated to the adjusted surface determined by the CP 3200 (for HDS 2500 it is thru only in one position of the reference blocks),
- are higher the angle differences of parallel planes of reference blocks determined by CP 3200.

In the case of reference cylinders have increasing character the differences between the measured and nominal diameters of the cylinders determined by HDS 2500.

General are achieved higher values by tests made for distances measured out of range given by the producers (50 m for the HDS and 32 m for the CP 3200).

4.3. The HOMOGENEITY test

The RB´s are scanned with the different part of the field of view of the tested TLS during this test. Because the position of RB´s is stabile, the head of the TLS was rotated to achieve the 9 different positions in the case of HDS 2500 and 6 positions in the case of CP 3200. To achieve the different vertical position of the RB in the case of CP 3200, the TLS was positioned in different levels. The distance between the RB and the TLS is the same during the whole test (10 m for the HDS 2500 and 3 m for the CP 3200).

During the HDS 2500 test are made scans in 2 positions (orientation) of the reference blocks and 2 positions of reference cylinders. In the case of CP 3200 are made only two scans - one for the reference blocks and one for the reference cylinders.

There are not achieved significant changes of the investigated parameters fort the both TLS, during the test. The differences between the determined and nominal parameters could be described with (table 6 and 7):

- 1,55 mm range for the dimension and 14,6´ range for angle values in the case of HDS 2500,
- 18,62 mm range for the dimension and 214,5´ range for the angle in the case of CP 3200.

Tab. 6 Differences between the model and nominal parameters – reference blocks (HDS 2500, CP 3200)

Differences to the		HDS 2500	CP 3200
		range of Δ	range of Δ
adjusted surface σ_{rez}	[mm]	0,08	1,06
nominal dimension	[mm]	1,06	5,78
parallelism	[´]	13,3	97,3
nominal amgle	[´]	14,6	167,7

Tab. 7 Differences between the model and nominal parameters – reference cylinders (HDS 2500, CP 3200)

Differences to the		HDS 2500	CP 3200
		range of Δ	range of Δ
adjusted surface σ_{rez}	[mm]	0,24	0,62
nominal diameter	[mm]	1,55	18,62
nominal high	[mm]	0,77	4,16
axis alignment	[´]	6,9	214,5

4.4. The MODEL POINT test

Parallel to the scanning of RB´s are made geodetic measurements by total station. The aim of these measurements is to define the 3D position accuracy of model points. To have the possibility of comparison of the TLS and total station determined points, transformation parameters are defined. For this the set of control points are installed around the RB´s in the space. Leica Geosystems reflecting prisms were used for this reason.

The geodetic measurements are made by Leica TCA 1101 total station, with the standard deviation of 5^{cc} in angle and 2 mm +2 ppm in distance measurement. The method of 3D intersection was used for the co-ordinate determination.

The differences between the co-ordinates of model points and the co-ordinates given by total station can be described with formula $|\Delta X| < \sigma_{\Delta X}$, $|\Delta Y| < \sigma_{\Delta Y}$, $|\Delta Z| < \sigma_{\Delta Z}$. According this the difference between the compared parameters is not significant (proved).

5. CONCLUSION

The designed and realised tests using RB´s bring the new dimension to the field of TLS testing. The shape and the dimension of the RB´s are designed and developed in co-operation whit the Department of Surveying of the TU Munich (Germany). The material and the colour of RB´s are chosen according to the high stability requirements. To give the RB´s in different position in the space are used the special holder, developed extra for this reason.

During the realised tests was achieved information about the quality of models produced by the camera view HDS 2500 and the panorama view CP 3200. However the used TLS are characterised by the producers with similar accuracy of model points and model surface, the test results show significant differences between their parameters.

According the results of realised tests the technology of TLS testing using reference bodies was developed. These enable the description of the detailed characteristics and the quality of the tested TLS, too. According the test results was defined the test schedule and the data processing which result to the unify test report. These include information about the tested TLS, their quality in numerical and graphical form.

The first results of TLS testing realised at the SUT in Bratislava are presented in the paper. The continue development of the developed technology are planed in the future. This could be oriented to design of another shape and geometry of the RB´s as well as the different laboratory conditions.

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