Field Procedures for Testing Terrestrial Laser Scanners (TLS)
A Contribution to a Future ISO Standard

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Key words: ISO 17123, Terrestrial Laser Scanner, Field Test Procedures

SUMMARY

ISO 17123 describes Field Test Procedures for different Geodetical Sensor Systems (e.g. Levels, Total Stations or GNSS-Systems). However, a standard for Terrestrial Laser Scanners (TLS) does not yet exist. Following the ISO 17123 philosophy, suggestions for simplified and full test procedures for TLS are given and proven through test measurements. The major aim of this contribution is to accelerate the discussion on TLS Field Test Procedures and the design process for a future ISO 17123 Part 9.

ZUSAMMENFASSUNG

Die ISO-Norm 17123 beschreibt Feldprüfverfahren für verschiedene geodätische Sensorsysteme (z.B. Nivelliere, Tachymeter, GNSS-Systeme). Für Terrestrische Laserscanner (TLS)gibt es bis jetzt keine standardisieren Prüfverfahren. Basierend auf der Grundphilosophie der ISO 17123 werden Vorschläge für einfache und umfassende Feldprüfverfahren gemacht. Die praktische Anwendbarkeit wird durch entsprechende Testmessungen nachgewiesen. Hauptziel dieses Beitrags ist es, die Diskussion über Feldtestverfahren für TLS sowie die Erstellung einer künftigen Teilnorm 9 der ISO 17123 zu beschleunigen.

Field Procedures for Testing Terrestrial Laser Scanners (TLS) A Contribution to a Future ISO Standard

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1. TEST PROCEDURES FOR TLS

More than 10 years ago the first field-suited Terrestrial Laserscanning Systems (TLS) were introduced onto the market. Since then these systems have established a firm place in the 'geodetic metrology toolbox'. The first suggestions for system calibrations, system tests and accuracy checks for TLS (e.g. Lichti 2000a, Lichti 2000b) were published at nearly the same time.

Most of the published investigations are based on more or less time-consuming field or laboratory tests (e.g. Kersten et. al. 2005, Staiger 2005, Wehmann 2007, Kern 2008, Mechelke 2008), which are hardly suitable for a simple and quick system test by the user on site. These (scientific) investigations could prove the limits and metrological particularities of the systems, however. As well, they showed valuable perceptions for the practical use of TLS.

The first considerations for simplified field tests for TLS were already made in 2001(Mueller, Wuersch 2001). Heister has taken up the topic on basis of the VDI recommendation 2634 (Optical 3D-Measuring Systems - …) and suggests standardized test procedures for TLS (Heister 2005). These suggestions do not completely correspond however to the basic philosophy of the ISO 17123 standard, which was published in 2001.

2. ISO 17123 – STRUCTURE AND BASIC PHILOSOPHY

Testing and checking of geodetic sensor systems using standardized test procedures has a long history. Examples are the German DIN 18723 (Field procedures for accuracy testing of geodetic instruments), the ISO 8332 (Building construction - Measuring instruments - Procedures determining accuracy in use, part 1 - 8) as well as the ISO 17857 (Optics and optical instruments - Field procedures for determining accuracy, part 2 - 4). Common to all these standards is that the potential user in practice has only very insufficient knowledge about them. The execution of the described procedures is mostly very time-consuming and therefore not very practical in use. The ISO TC172 SC6 started to discuss more user-friendly test procedures already in about 1985.

In 1994 the FIG commission 5 WG 5.1 under the direction of J.-M. Becker recommended '*Procedures for Routine Checks of Electro-Optical Distance Meters (EDM)'* (FIG 1994). These recommendations - with a trailblazing cost-use-optimized test strategy - gave among other things the impetus for a new ISO standard (Huep 2001, Gottwald 2001, Zeiske 2001) - *ISO 17123 Field procedures for testing geodetic and surveying instruments* - which was published between 2001 and 2007 in 8 parts.

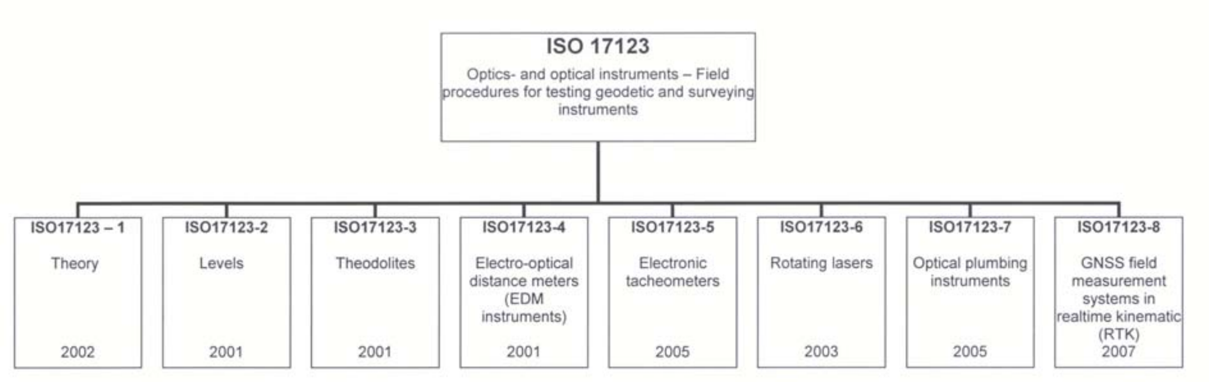

Fig. 1 Structure of ISO17123

In order to define practice-suited and user-friendly test procedures for the respective sensor systems, ISO 17123 is split into 'simplified test procedures' and 'full test procedures'.

'Simplified test procedures'
- Supervises the adherence to a given deviation with a minimized time consumption for measurements and evaluation
- The computed standard deviations are based on a small sample size. The significance of these values is very limited

'Full test procedures'
- Due to a larger sample size the computed experimental standard deviations are significant for the evaluation of the measurement accuracy.
- The computed (experimental) standard deviations can be compared on the basis of statistical tests (with the specified given value [manufacturer’s specification], with another test set up with the same instrument, with the same instrument in another setup and with another operator, with an earlier or later test setup, with a setup in the same constellation but another instrument, …).
- The calculation equations required for the data processing of the 'full test procedures' are given in each sub part of ISO 17123.

3. A CONTRIBUTION TO A NEW ISO STANDARD FOR TLS

With the publication of ISO standard 17123 part 8 (GNSS field measurement systems in real time kinematic (RTK)) in September 2007, TLS are the only remaining geodetical measuring systems without standardized field test procedures. In accordance with the chair of ISO TC172/SC6 and with support of Leica Geosystems AG Heerbrugg, Switzerland basic ideas for simplified and full field test procedures for TLS have been worked out in a diploma thesis at the University of Applied Sciences Northwestern Switzerland (Rothweiler and Schmid 2007). For the test measurements, 3 TLS (1 Leica ScanStation 2, 1 Leica HDS6000 (both well calibrated) and 1 Leica ScanStation 2 (not calibrated) were used.

In the following chapters the most important results from the thesis are summarized with the main focus on the simplified field test procedures.

3.1 Simplified Test Procedures

In the sense of the basic philosophy of the ISO 17123 standard, the following boundary conditions were given for the development of possible simplified test scenarios for TLS:

- independent of the functional principle (panoramic-, camera-view-, time of flight-, phase measurement-TLS)
- secure detection of distance and/or angle deviations
- use of standard measurement equipment only (i.e. no use of additional reference sensors, e.g. total station or special test equipment)
- maximum time needed for measurements, evaluation and final decision less than 1 hour

3.1.1 Single Distance Procedure (SDP)

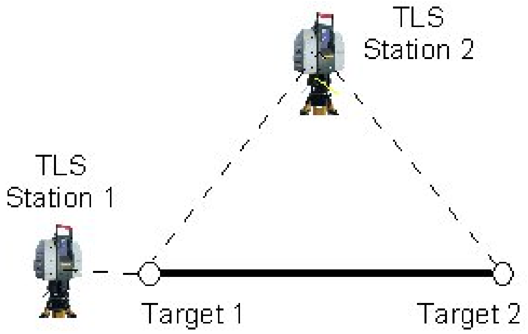

Fig. 2 Single Distance Procedure (SDP)

Test Field and test procedure:

- Set up a test line 1 – 2; distance 1 – 2 according to the desired range (SDP1: 1 – 2 nearly horizontal; SDP2: 1 – 2 with a significant height difference)
- Set up TLS in station 1 in line with target 1 and 2; measure targets 1 and 2 (setup 1)
- Set up TLS in station 2 perpendicular to line 1 – 2; measure targets 1 and 2 (setup 2)
- Calculate distance 1 – 2 out of setup 1 and 2; compare the distance difference with the permitted deviation -> decision ok/not ok

3.1.2 Crossed Double Distance Procedure (CDP)

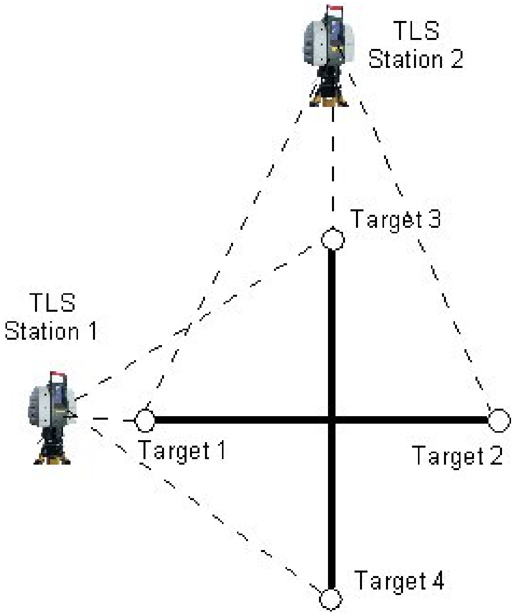

Fig. 3 Crossed Double Distance Procedure (CDP)

Test Field and test procedure:
- Set up two perpendicular test lines (1 - 2, 3 – 4); distances according to the desired range (CDP1: targets 1 – 4 in a nearly horizontal plane; CDP2: target 2 or 4 at a significantly different height than the other 3 targets)
- Set up TLS in station 1 in line with target 1 and 2; measure targets 1 – 4 (setup 1)
- Set up TLS in station 2 in line with target 3 and 4; measure targets 1 – 4 (setup 2)
- Calculate distance 1 – 2 and 3 – 4 out of setup 1 and 2; compare the distance difference with the permitted deviation -> decision ok/not ok

With CDP2 it is possible to determine a deviation in the vertical angle measurement too.

3.1.3 Triangle Procedure (TP)

Test Field and test procedure:
- Set up three targets in a nearly equal-leg triangle; distances according to the desired range; (one of the corner points should be at a significantly different height)
- Set up TLS in station 1; measure targets 1 – 3 (setup 1)
- Set up TLS in station 2; measure targets 1 – 3 (setup 2)
- Calculate distances 1 – 2, 1 - 3 and 2 – 3 out of setup 1 and 2; compare the distance difference with the permitted deviation -> decision ok/not ok

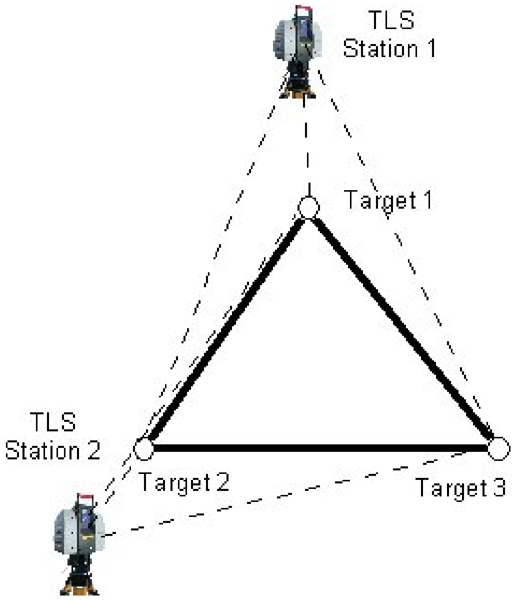

Fig. 4 Triangle Procedure (TP)

3.1.4 Triangle Star Procedure (TSP)

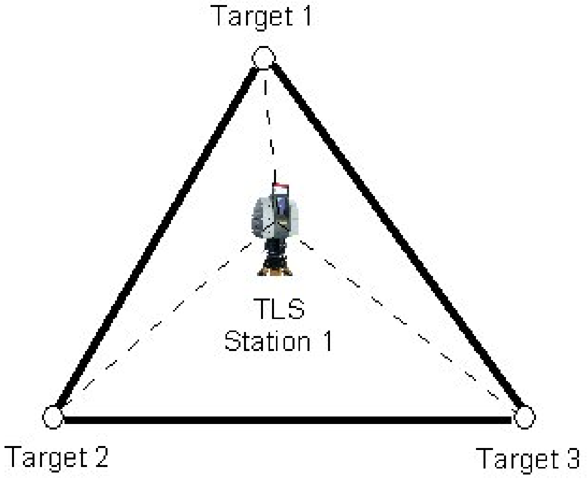

Fig. 5 Triangle Star Procedure (TSP)

- Set up three targets in a nearly equal-leg triangle; distances according to the desired range; (one of the corner points should be at a significantly different height)
- Set up TLS in station 1; measure targets 1 – 3
- Determine distances 1 – 2, 1 – 3, 2 – 3, TLS – 1, TLS – 2 and TLS3
- Calculate distances 1 – 2, 1 - 3 and 2 – 3 out of scanning data; compare the calculated with the determined distances and check the distance differences with the permitted deviation -> decision ok/not ok

This suggested procedure was rejected before the execution of test measurements due to high correlations between distances and angles for the computation of distances 1-2, 1-3 and 2-3 from the scanning data.

3.1.5 Test Measurements and Evaluation

The feasibility of the ideas for simplified field tests of TLS described in the previous chapters was proven in practical field tests. Due to operational reasons the measurements with the uncalibrated TLS (=SS2nc) had to be carried out in a separate setup, so that the measured distances do not correspond with the calibrated system measurements (ScanStation2 = SS2, HDS6000 = 6000). The tolerance value for a distance difference is computed on the assumption of a point accuracy of 4.0 mm for a scanned target and a significance level S = 99%. The test setups had been additionally referenced with a Leica TCRP1201 total station.

Single Distance Procedure (SDP)

Procedure	TLS	Line	TLS Station 1 [m]	TLS Station 2 [m]	Δ=S1-S2 [mm]	Tolerance S=99% [mm]	Reference TCRP1201 [mm]
SDP1	SS2	1-2	44.198	44.199	-1	14	44.203
	6000	1-2	-	-	-	-	-
	SS2nc	1-2	-	-	-	-	-
SDP2	SS2	1-2	44.900	44..899	1	14	44.905
	6000	1-2					
	SS2nc	1-2					
Total time	< 60 min						

pro:	independent of the functional principal; use of standard measurement equipment only; easy to perform; total execution time < 60 minutes
con:	no redundancy; no independent control

Crossed Double Distance Procedure (CDP)

Procedure	TLS	Line	TLS Station 1 [m]	TLS Station 2 [m]	Δ=S1-S2 [mm]	Tolerance S=99% [mm]	Reference TCRP1201 [mm]
CDP1	SS2	1-2	43.046	43.046	0	14	43.049
		3-4	47.478	47.481	-3		47.481
	6000	1-2	43.050	43.048	2	14	43.049
		3-4	47.485	47.483	2		47.481
	SS2nc	1-2	42.812	42.724	***88***	14	42.925
		3-4	47.009	47.105	***-96***		47.226
Procedure	TLS	Line	TLS Station 1 [m]	TLS Station 2 [m]	Δ=S1-S2 [mm]	Tolerance S=99% [mm]	Reference TCRP1201 [mm]
CDP2	SS2	1-2	43.046	43.046	0	14	43.049
		3-4	45.911	45.911	0		45.913
	6000	1-2	43.050	43.048	2	14	43.049
		3-4	45.913	45.914	-1		47.481
	SS2nc	1-2	42.812	42.724	***88***	14	42.925
		3-4	45.136	44.917	***219***		45.032
Total time	≈60 min						

pro:	independent of the functional principal; use of standard measurement equipment only; easy to perform; total execution time approx. 60 minutes, independent control
con:	-

Triangle Procedure (TP)

Procedure	TLS	Line	TLS Station 1 [m]	TLS Station 2 [m]	Δ=S1-S2 [mm]	Tolerance S=99% [mm]	Reference TCRP1201 [mm]
TP1	SS2	1-2	45.595	45.598	-3	14	45.597
		2-3	47.478	47.481	-3		47.481
		3-1	36.051	36.051	0		36.055
	6000	1-2	45.599	45.598	1	14	45.597
		2-3	47.485	47.483	2		47.481
		3-1	36.055	36.049	6		36.055
	SS2nc	1-2	42.674	42.671	3	14	42.787
		2-3	47.009	47.105	***-96***		47.226
		3-1	36.828	36.758	***70***		36.931

Triangle Procedure (TP) cont.

TP2	SS2	1-2	45.595	45.598	-3	14	45.597
		2-3	45.911	45.911	0		45.913
		3-1	39.758	39.759	-1		39.762
	6000	1-2	45.599	45.598	1	14	45.597
		2-3	45.913	45.914	-1		45.913
		3-1	39.762	39.757	5		39.762
	SS2nc	1-2	42.674	42.671	3	14	42.787
		2-3	45.136	44.917	***219***		45.032
		3-1	40.280	40.475	***-195***		40.386
Total time	≈60 min						

pro:	independent of the functional principal; use of standard measurement equipment only; easy to perform; total execution time approx. 60 minutes, independent control
con:	-

3.1.6 Recommendations

In principle both multiline-procedures (CDP, TP) are suitable for a simplified field test of TLS. It is favorable to use sphere targets instead of plane targets. The procedures with a significant height difference in the test setup is to be preferred (CDP2, TP2), because deviations in the vertical angle measurement can be detected.

Fig. 6 Sphere target

To optimize the detection of zero-point errors of the TLS rangefinder, a slight modification of CDP and TP related to TLS station 2 is suggested (see fig 6).

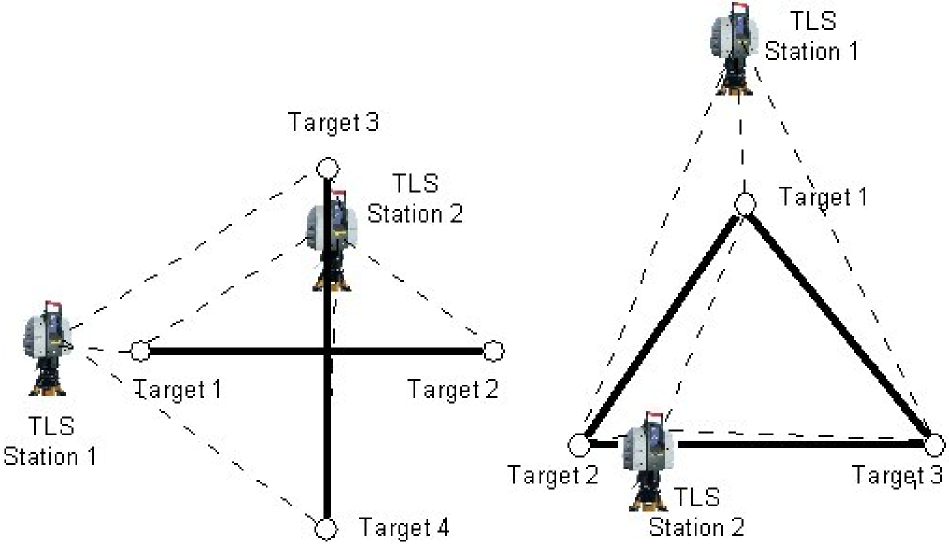

Fig. 7 Optimized CDP and TP setup

3.2 Full Test Procedures

The following boundary conditions are given for a full test procedure for TLS:

- more or less independent of the functional principal of the tested TLS
- use of reference sensor systems and/or fixed test setups is possible
- significant evaluation of accuracy und systematic deviations based on statistical processes
- maximum time needed for measurements, evaluation and final decisions less than ½ day

3.2.1 Parameters to be determined

In the context of a comprehensive test, a whole set of test parameters has to be determined (see e.g. Heister 2006, Kern 2008, Kersten et.al 2005, Staiger 2005, …)

The most important test parameters are:
- probing error
- spacing error
- flatness measurement error
- target error
- angle measurement deviation
- zero point error (range finder)
- scaling error (range finder)
- target offsets and sphere diameter

3.2.2 Full Test Approach

For the full test procedure a modular approach is suggested to also enable scanner-specific tests. In this paper only the general approach is introduced, without dealing with the characteristics of specific scanner types (e.g. geodetic scanner, non geodetic scanner....) in relation to the test procedure.

Basic-Module

The Basic-Module covers the determination of the following deviations:
probing error, spacing error, target error, angle measurement deviation

It is suggested to set up a network with a minimum of 6 points which fulfill the following conditions:
- the network should cover the minimum and maximum range of the TLS
- the points should be distributed over the horizon as far as possible
- one point should be on a significantly different height level (preferably point 1, see Fig. 8)
- the network has to be referenced with an accuracy as high as possible (preferably with a total station)

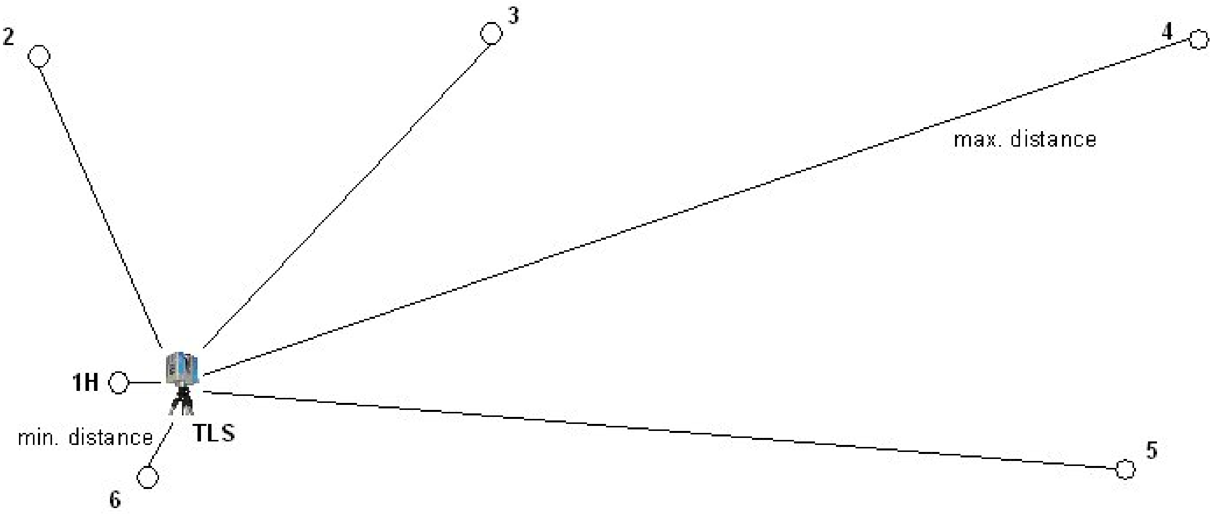

Fig. 8 Test setup 'full test procedure' – basic module (1H – target at a significantly different height)

The evaluation (probing error, spacing error) can be done with formulas given by Heister 2006. The target error can be determined out of a Helmert transformation (reference data vs. scanning data).

Add-on Module 1 - zero point error (range finder)

To determine a zero point error of the TLS range finder unit, the classic EDM-baseline approach is suggested. This test can be performed with TLS with forced centering only.

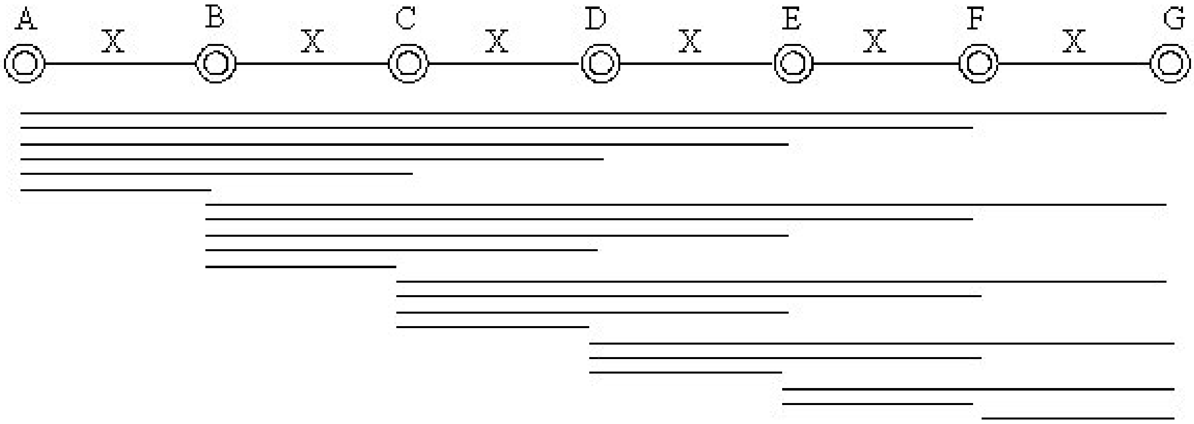

Fig. 9 Test setup 'zero-point error' (Rothweiler, Schmid 2007)

Add-on Module 2 - flatness measurement error

To determine the flatness measurement error, the use of a precisely tiltable plane is suggested. This can be measured (see e.g. Kersten 2005, Mechelke 2008) in single setups at different distances or in the basic test network (forced centering required).

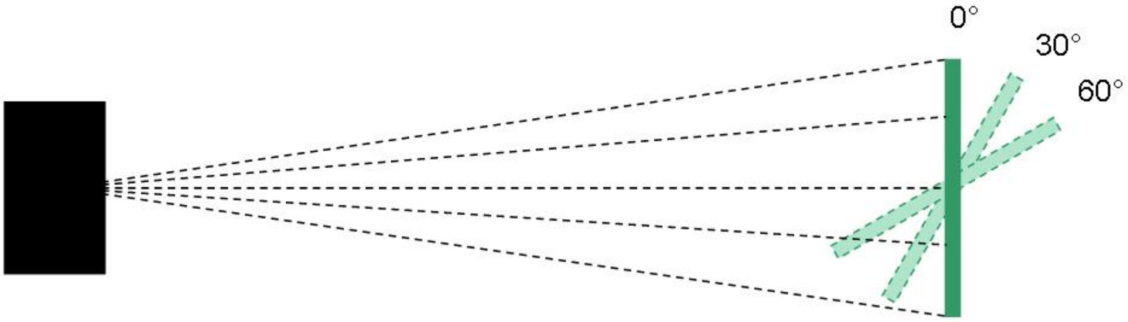

Fig. 10 Test setup 'flatness measurement error' (Rothweiler, Schmid 2007)

4. CONCLUSION

It has been proven that it is possible to set up suitable simplified and full test procedures for TLS in the manner of the ISO17123 basic philosophy. It is recommended to use the Crossed Double Distance Procedure (version 2 – CDP2) as the simplified procedure und the basic-module for the full test procedure. It is not recommended to incorporate the add-on modules into a future ISO-standard.

Hopefully the discussion about such a new standard will lead to the design of a suitable standard as fast as possible so that standardized and practice-suited test procedures will be available for the user in practice. These should naturally be implemented then by the system manufacturers into their scansoftware.

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BIOGRAPHICAL NOTES

Reinhard Gottwald is professor for geodetic metrology and head of the Institute of Geomatic Engineering at the University of Applied Sciences Northwestern Switzerland (FHNW). He received his diploma in geodesy at the University Bonn, Germany in 1975 and his 'Vermessungsassessor' in 1978. After 3 years of practical work at a publicly appointed surveyors' office, he went back to university as a research assistant. He received his PhD from the RWTH Aachen University in 1984. After 7 years in industry (project management, R&D management) he was appointed as professor at the Basel University of Applied Sciences (now FHNW). He is a member of the board of directors of the FHNW School of Architecture, Civil Engineering and Geomatics and of several national and international organizations.

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