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Determination of Angular Standard Deviation with Total Stations

1. Introduction

Periodic verification of the measuring accuracy of surveying instruments is becoming increasingly important, be it by the desire of the user or a by the contractor to meet stipulated instrument accuracy requirements for a given contract. The ISO standards, contain rigorous field methods to test surveying instruments that are similar to each other. Beside the full testing method, the ISO standard also offers a simplified method.

The correctness of these methods is beyond any doubt, in practical application however, the following problems may occur:

- finding a suitable testing area (shortage of space, driving distance to the testing area, etc.);
- the time consumed in setting up the testing equipment for just a single or occasional test;
- the costs of a permanent installation;
- the time it takes to carry out the measurements.

These problems are particularly prevalent at service workshops for surveying instruments located in greater metropolitan areas, where free space is in short supply. Other institutions may also be confronted with similar problems. Described below is the so-called compact laboratory testing method recommended to all institutions and service workshops and optimized to eliminate the above listed problems.

2. Measuring Setup

In planing the measuring setup, special attention was given to limiting space and time requirements for carrying out the measurements.

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2.1. Horizontal and Vertical Angles Measuring Setup

The instrument is set in a tribrach firmly mounted on a steel or concrete pillar. Angular measurement is done using five collimators which are arranged according to the illustration below (Fig. 1). Two of the collimators are placed in the horizontal direction and the other three outside of it covering an elevation angle of +30° to –40°. The reason for this arrangement is to optimize the time it takes for the measuring process. Horizontal and vertical measurements, otherwise carried out in separate steps, are done in a single step. The cross hairs of the collimator are pointed to centrically enabling simultaneous horizontal and vertical angle measurements. This procedure is justified with laboratory methods, as atmospheric influences such as refraction, heat shimmer and temperature differences are non-existent.

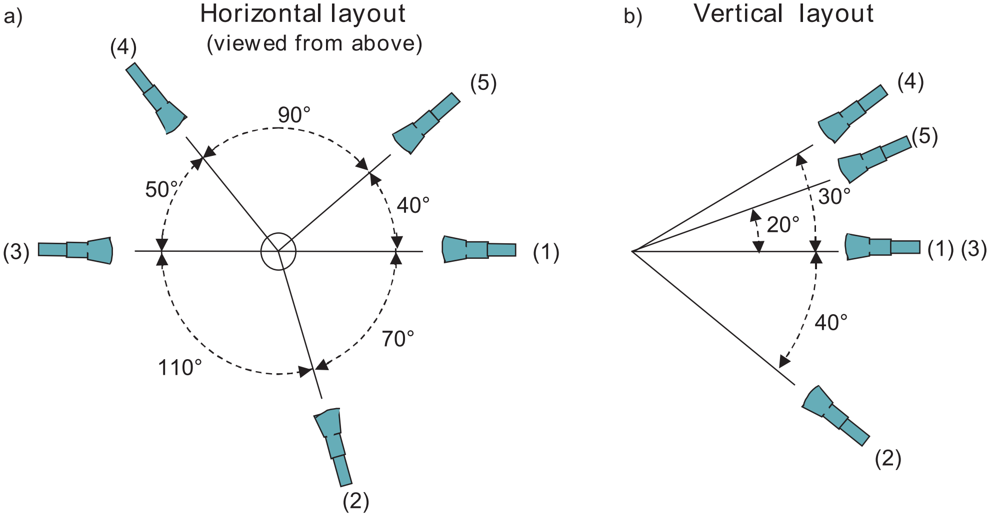

Fig. 1. Horizontal (a) and vertical (b) arrangement of the collimators for angular measurements

2.2. Angular Measurements

Before starting a measurement, the instrument must be brought to ambient temperature. Line-of-sight, tilting axis, vertical index and zero point error of the compensator can be adjusted for cosmetic reasons but do not influence accuracy due to two/double face measurements as long as they remain constant during the measurement period.

One serie of three sets of angles is done in both faces to the five collimators. The collimators are targeted in the center as the horizontal and vertical angles are measured together in the same work process. The first half set is taken clockwise and the second half set counter-clockwise. Between each set of measurements the instrument is removed from the tribrach, turned by 120°, inserted back, and clamped. With this procedure errors in the angular measurement system can be detected.

Determining the experimental standard deviation is done separately for the horizontal directions and vertical angles according to the known formula for measuring sets of angles.

The experimentally determined standard deviation $s(Hz)$, of a horizontal direction measured once in both faces is calculated as follows:

$$x(Hz) = \sqrt{\frac{\sum_{i=1}^{3}\sum_{j=1}^{5} r_{i,j}^2}{8}},$$

where:

i – number of sets,
j – number of target points,
$r_{i,j}$ – residuals of the measured Hz-directions to the average of the set.

The experimentally determined standard deviation $s(V)$ of a vertical angle measured once in both faces is calculated as follows:

$$s(V) = \sqrt{\frac{\sum_{i=3}^{3}\sum_{j=1}^{5} r_{i,j}^2}{10}},$$

where:

i – number of sets,
j – number of target points,
$r_{i,j}$ – residuals of the measured V-angles to the average of the set.

The question of interest is now if the experimentally determined standard deviations correspond to the manufacturer´s specifications.

Using the common hypotheses test procedures in statistics, it is possible with a level of significance of 95% for both degrees of freedom f of 8 and 10, to set a commonly valid (rounded) quantile of 1.3:

$$\sqrt{\frac{\chi^2(95\%, f)}{f}} \geq 1.3.$$

This means that if the experimental standard deviation is 1.3 times the manufacturer's specifications, the instrument is rated as not qualified with a remaining risk factor of 5% that it might have been acceptable.

3. Evaluation Software

To optimize evaluation, an evaluation software was written (Windows OS) that, besides enabling manual input for opto-mechanical instruments, also features automatic data acquisition for electronic total stations. The user is not only guided through the measuring procedures described above, but is also notified if gross errors occur, like pointing to wrong targets. The measured values and the results can be printed as reports.

During *V*-angle measurements the index errors and during *Hz*-direction measurements the collimator errors are displayed and used to check the measured values for gross errors (Fig. 2). A possible eccentricity of the horizontal circle can be determined from the values of the collimation error (Fig. 3).

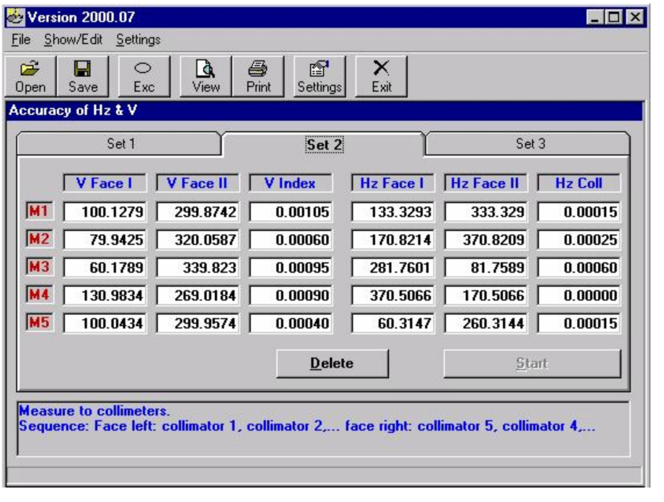

Fig. 2. Combined *Hz*-direction and *V*-angle measurements

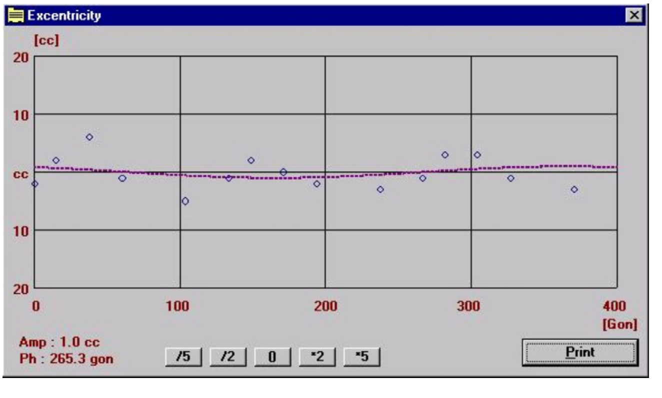

Fig. 3. Graph of the *Hz*-circle eccentricity

The graph permits easy interpretation of the error. On instruments with diametrical angle reading device this is of course only noise within the range of accuracy of the instrument as use of diametrical reading devices eliminates this error.

The reports contain the measurements as well as the results of the evaluations as shown in the examples below for angular measurement (Fig. 4).

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********** Combined Hz-V angle measurement **********
    Product: TC2003
    Temperature: 24 +/-5 C
    Serial No: 438315
    Inspection date: 22.10.01
    Inpected by: DZ
    Remark 1: Neue Anlage-Geo
    Remark 2:
    Standard deviation (s): 0.15 mGon
    Unit : Gon
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Hz Measurement :

	Hz face 1 [gon]	Hz face 2 [gon]	Hz Coll [gon]	Hz Mean [gon]	Reduced Mean [gon]	Mean of all [gon]	v [mGon]
Values of Set 1							
01	.03130	200.03110	.00010	.03120	.00000	.00000	.03667
02	37.52450	237.52270	.00090	37.52360	37.49240	37.49225	-.11333
03	148.46190	348.46090	.00050	148.46140	148.43020	148.43032	.15333
04	237.20890	37.20890	.00000	237.20890	237.17770	237.17765	-.01333
05	327.01700	127.01660	.00020	327.01680	326.98560	326.98550	-.06333
Values of Set 2							
01	133.32930	333.32900	.00015	133.32915	.00000	.00000	-.10333
02	170.82140	370.82090	.00025	170.82115	37.49200	37.49225	.14667
03	281.76010	81.75890	.00060	281.75950	148.43035	148.43032	-.13667
04	370.50660	170.50660	.00000	370.50660	237.17745	237.17765	.09667
05	60.31470	260.31440	.00015	60.31455	326.98540	326.98550	-.00333
Values of Set 3							
01	266.69270	66.69230	.00020	266.69250	.00000	.00000	.06667
02	304.18540	104.18430	.00055	304.18485	37.49235	37.49225	-.03333
03	15.12340	215.12240	.00050	15.12290	148.43040	148.43032	-.01667
04	103.87010	303.87050	-.00020	103.87030	237.17780	237.17765	-.08333
05	193.67810	393.67790	.00010	193.67800	326.98550	326.98550	.06667

Result Hz : 0.12 [mGon]

V Measurement :

	V face 1 [gon]	V face 2 [gon]	V Index i [gon]	Z I+(P-II)/2 [gon]	Mean of all [gon]	v [mGon]
Values of Set 1						
01	100.12740	299.87420	.00080	100.12660	100.12675	.15000
02	79.94280	320.05880	.00080	79.94200	79.94190	-.10000
03	60.17870	339.82310	.00090	60.17780	60.17795	.15000
04	130.98270	269.01800	.00035	130.98235	130.98237	.01667
05	100.04370	299.95730	.00050	100.04320	100.04310	-.10000
Values of Set 2						
01	100.12790	299.87420	.00105	100.12685	100.12675	-.10000
02	79.94250	320.05870	.00060	79.94190	79.94190	.00000
03	60.17890	339.82300	.00095	60.17795	60.17795	.00000
04	130.98340	269.01840	.00090	130.98250	130.98237	-.13333
05	100.04340	299.95740	.00040	100.04300	100.04310	.10000
Values of Set 3						
01	100.12760	299.87400	.00080	100.12680	100.12675	-.05000
02	79.94240	320.05880	.00060	79.94180	79.94190	.10000
03	60.17920	339.82300	.00110	60.17810	60.17795	-.15000
04	130.98330	269.01880	.00105	130.98225	130.98237	.11667
05	100.04360	299.95740	.00050	100.04310	100.04310	.00000

Result V : 0.12 [mGon]

Fig. 4. Report of a *Hz*-direction and *V*-angle measurement

4. Results and Comparisons

A comparison of results obtained with the same instruments applying different test methods shows the efficiency, reliability, and limitations of this compact laboratory method.

The table 1 show a comparison of the accuracy attained for angles.

Table 1. Accuracy comparison for angles

Type of instrument	Angle	Accuracy			
		compact method [mgon]	ISO in the field [mgon]	ISO in the lab [mgon]	manufacturer specification [mgon]
TC 2003	*Hz* *V*	0.12 0.12	0.15 0.14	0.11 0.11	0.15 0.15
TCRA 1102	*Hz* *V*	0.49 0.26	0.36 0.35	0.37 0.17	0.60 0.60
TCR 303	*Hz* *V*	0.54 0.50	0.50 0.66	0.34 0.37	1.0 1.0
TC 605	*Hz* *V*	0.86 0.76	0.89 0.80	0.67 0.52	2.0 2.0

The ISO method in the laboratory follows the same procedures as in the field except that only collimators are used for the measurements.

5. Closing Remarks

A laboratory method to test the accuracy of instruments was shown that has been optimized in regards to time and space requirements. The time gained (factor 5) compared to the rigorous field method was made possible by combining the *Hz*-direction and the *V*-angle measurements.

It pays to use this method for occasional checks of individual instruments. It is recommended for a large number of instruments as in the case of e.g. service workshops and to “student educate”.