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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  $+30^\circ$  to  $-40^\circ$ . 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 centrally 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.

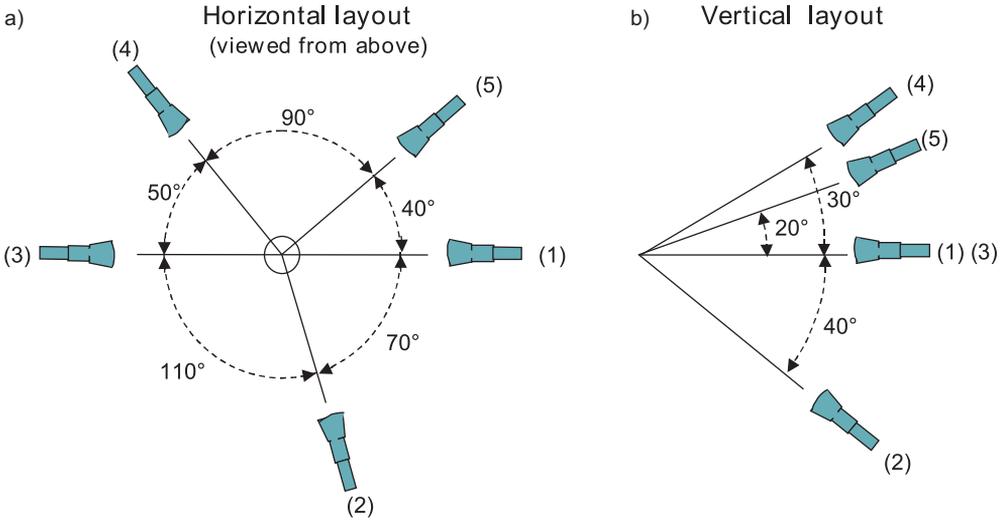


Fig. 1. Horizontal (a) and vertical (b) arrangement of the collimators for angular measurements

### 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  $120^\circ$ , 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:

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

where:

$i$  – number of sets,

$j$  – number of target points,

$r_{i,j}$  – residuals of the measured  $H_z$ -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).

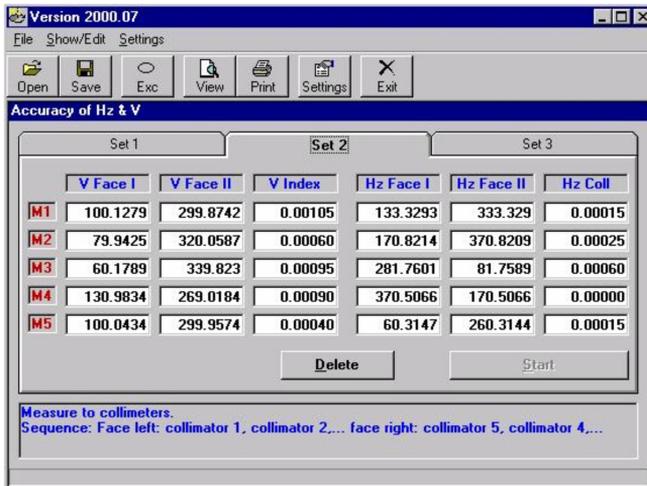


Fig. 2. Combined *Hz*-direction and *V*-angle measurements

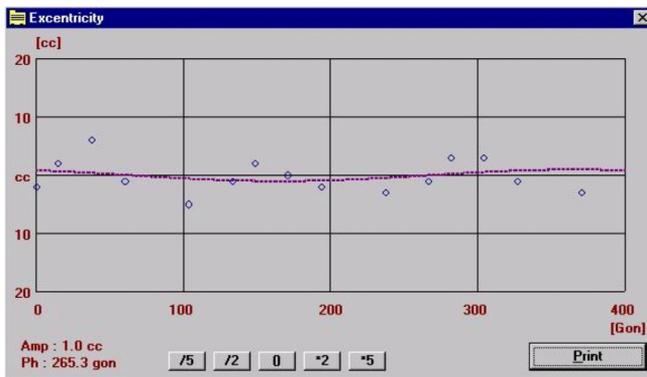


Fig. 3. Graph of the *Hz*-circle eccentricity

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
Inspected by: DZ
Remark 1: Neue Anlage-Geo
Remark 2:
Standard deviation (s): 0.15 nGon
Unit : Gon
*****

Hz Measurement :
      Hz      Hz      Hz      Hz      Reduced      Mean      v
      face 1   face 2   Coll   Mean   Mean      of all      v
      [gon]   [gon]   [gon]   [gon]   [gon]   [gon]   [nGon]
-----
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

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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

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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 [nGon]

V Measurement :
      V      V      V Index      Z      Mean      v
      face 1   face 2   i      I+(P-III)/2   of all      v
      [gon]   [gon]   [gon]   [gon]   [gon]   [nGon]
-----
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

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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

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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 [nGon]
    
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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	<i>Hz</i>	0.12	0.15	0.11	0.15
	<i>V</i>	0.12	0.14	0.11	0.15
TCRA 1102	<i>Hz</i>	0.49	0.36	0.37	0.60
	<i>V</i>	0.26	0.35	0.17	0.60
TCR 303	<i>Hz</i>	0.54	0.50	0.34	1.0
	<i>V</i>	0.50	0.66	0.37	1.0
TC 605	<i>Hz</i>	0.86	0.89	0.67	2.0
	<i>V</i>	0.76	0.80	0.52	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”.