TESTING THE CONSTANCY OF THE TARGET AXIS WITH A CHANGE IN FOCUSING IN PRECISE THEODOLITES AND ELECTRONIC TACHEOMETERS

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1. INTRODUCTION

One of the most accurate methods of testing the geometry of industrial objects is that of angle intersection. The accuracy obtained by this method in the case of small objects amounts to several hundredths millimetres. Unfortunately, high theoretical accuracy of angular measurements with short targets is limited by the vacillation of the target axis induced by focusing changes. The mechanism of this phenomenon is shown in the figure below:

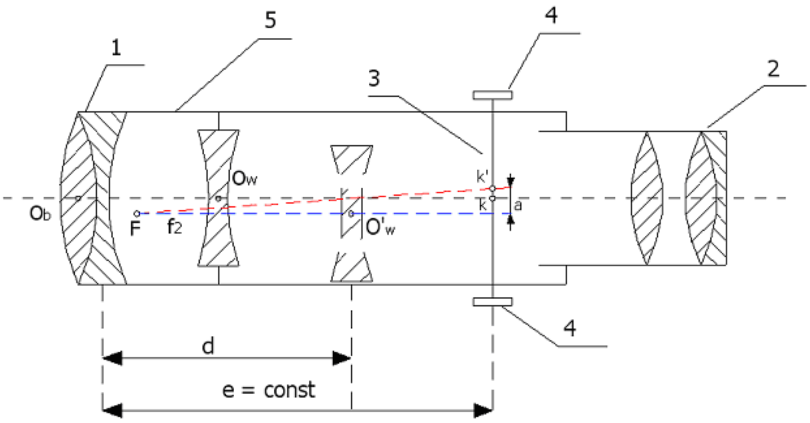

Fig. 1. Diagram of a telescope.

Diagram description: 1 – objective lens; 2 – eyepiece lens;3 – focal cross-hairs plate; 4 – rectifying thumbscrews of the focal plate;
telescope tube: e – const; f_2 – focus of the inner focusing lens

Due to errors of the focusing mechanism, with a change in focusing, lens O_w will take up position O'_w, deflected from the target axis by value a. In this position, light ray O_bO_w, having gone through the dispersing lens, will deflect from the original direction and pierce the focusing plate at point k'. The focusing error resulting from the malfunctioning focusing mechanism will amount to:

$$kk' = \frac{e-d}{f_2}a$$

This phenomenon will become all the more prominent with the target range of several metres and stems from a greater movement of the inner focusing lens in the instrument's telescope. Movements of the target axis in relation to the telescope are

demonstrated by value changes in collimation error and zero point of the vertical circle.
In order to check the character and size of this phenomenon a series of tests were carried out for a selected number of instruments. The measurements were made as part of a Master's dissertation project by Łukasz Pogodziński, (Pogodziński Ł. 2002).

2. MEASUREMENT ORGANIZATION AND PERFORMANCE

Five instruments were tested. They were electronic theodolites Wild T1600, Wild T2002 (2 specimens) and two tacheometers Wild TC1610 and Leica TCM1800. The studies of target axis changes were made by checking collimation changes and zero position of the vertical circle. The measurements were carried out in six series, and at the same time, collimation (horizontal circle) and zero point (vertical circle) errors were determined.
The distance covered by the inner focusing lens can be defined by the following equation:

$$\Delta d = \frac{f_1^2(\lambda_\infty - f_2)^2}{(D - f_1)(2f_2 + \lambda_\infty)\lambda_\infty}$$

where :
f_1 , f_2 - focuses of the objective and inner focusing lenses,
λ_∞ - distance between the inner focusing lens and the aiming cross plane ,
D – distance between an object and the objective lens (target length).
For T2 theodolite we obtain folowing values:

D(m)	1.5	2.0	5.0	10.0	20	50	100	200	500
Δd(mm)	14.3	10.5	4.06	2.00	1.00	0.40	0.23	0.07	0.04

As the inner focusing lens covers most of its movement range with short targets, measurements of higher density were appropriately assumed for targets up to 10m. For long targets the lens movement in the plane perpendicular to the movement direction is highly improbable so the number of measurements was significantly smaller.

3. RESULTS OF TARGET AXIS CONSTANCY STUDIES FOR SELECTED INSTRUMENTS

3.1. Electronic theodolite Wild T 1600

A series of tests was carried out for seven target lengths. The measurement results are presented in the table below. The position of the target axis for the longest target (240m) was assumed to be our reference, roughly corresponding to infinity.

Table 1. Measurement results for Wild T 1600 theodolite.

	D [m]	k [cc]	M_0 [cc]	k_{oo} [cc]	M_{oo} [cc]	m_k[cc]	m_M [cc]
1.	1,62	-0,4	1,3	8,9	60,7	0,6	0,7
2.	1,91	-3,1	-23,4	6,3	36,0	0,7	0,5
3.	2,58	-3,8	-41,1	5,5	18,3	0,5	0,7
4.	3,75	-6,1	-52,1	3,2	7,3	0,4	0,9
5.	5,32	-6,9	-57,7	2,4	1,7	0,2	0,3
6.	14,90	-7,5	-58,8	1,8	0,7	0,5	0,5
7.	240,00	-9,3	-59,4	0,0	0,0	0,5	0,9

Table legend:
D – target length,
k - original collimation value,
M_0 - original value of zero point of the vertical circle,
k_∞ - collimation value reduced to D= ∞,
M∞ - value of zero point reduced to D=∞,
m_k , m_M - mean errors of determining collimation and zero point in six series.

A change in the position of the target axis is illustrated by the following diagrams. For the sake of clarity, target lengths (horizontal axis) were shown in the logarithmic scale.

3.2. Electronic theodolite Wild T 2002 No 346352

A series of tests was done for nine target lengths. The results are presented in the table and two diagrams below.

Table 2. Measurement results for Wild T 2002 (1) theodolite.

	D [m]	k [cc]	M_0 [cc]	k_{oo} [cc]	M_{oo} [cc]	m_k[cc]	m_M [cc]
1.	1,62	-53,1	34,8	-32,9	28,5	0,6	0,4
2.	2,00	-59,7	42,9	-39,5	36,6	0,8	0,3
3.	3,00	-30,6	15,3	-10,3	9,0	0,8	0,7
4.	4,10	-25,9	16,3	-5,6	9,9	0,6	0,7
5.	6,00	-21,0	10,6	-0,7	4,3	0,4	0,5
6.	10,20	-19,1	9,1	1,2	2,8	0,4	0,8
7.	20,50	-21,1	9,5	-0,9	3,2	0,4	0,4
8.	38,30	-19,3	8,8	1,0	2,5	0,4	0,5
9.	240,00	-20,2	6,3	0,0	0,0	0,6	0,6

3.3.Electronic theodolite Wild T 2002 No 346348

A series of tests was carried out for nine lengths

Table 3. Measurement results for Wild T 2002 (2) theodolite.

	D [m]	k [cc]	M_0 [cc]	k_{oo} [cc]	M_{oo} [cc]	m_k[cc]	m_M [cc]
1.	1,62	36,0	11,8	37,4	5,7	0,7	0,5
2.	2,30	23,8	4,5	25,2	-1,6	0,6	0,6
3.	3,34	9,6	7,9	11,1	1,8	0,5	0,4
4.	5,20	5,6	1,8	7,1	-4,3	0,6	0,8
5.	8,20	0,7	3,1	2,1	-3,0	0,6	0,7
6.	13,80	3,6	7,4	5,1	1,3	0,7	0,7
7.	27,60	5,7	2,7	7,2	-3,4	0,6	0,7
8.	41,40	5,6	5,4	7,0	-0,7	0,5	0,5
9.	240,4	-1,4	6,1	0,0	0,0	0,4	0,7

3.4. Electronic tacheometer Wild TC 1610

A series of tests was carried out for seven lengths.

Table 4. Measurement results for Wild TC 1610 tacheometer.

	D [m]	k [^{cc}]	M_0 [^{cc}]	k_{oo} [^{cc}]	M_{oo} [^{cc}]	m_k [^{cc}]	m_M [^{cc}]
1.	1,57	40,0	5,7	20,5	90,1	0,8	0,7
2.	1,95	33,4	-13,9	13,9	70,4	0,7	0,6
3.	3,07	28,8	-45,1	9,3	39,3	0,7	0,6
4.	5,00	27,5	-63,6	8,0	20,7	0,7	0,7
5.	7,40	23,5	-63,5	4,0	20,8	0,5	0,9
6.	15,20	21,8	-76,7	2,2	7,7	0,6	0,4
7.	240,00	19,5	-84,3	0,0	0,0	0,7	0,7

3.5. Electronic tacheometer Leica TCM 1800

A series of tests was carried out for nine lengths.

Table 5 Measurement results for Leica TCM 1800 tacheometer.

	D [m]	k [^{cc}]	M_0 [^{cc}]	k_{oo} [^{cc}]	M_{oo} [^{cc}]	m_k [^{cc}]	m_M [^{cc}]
1.	1,65	14,0	29,1	17,2	39,0	0,6	0,6
2.	2,15	15,3	23,8	18,6	33,8	0,6	0,7
3.	3,15	12,2	15,9	15,4	25,8	0,5	0,6
4.	4,50	15,3	9,8	18,6	19,8	0,6	0,6
5.	6,20	11,1	7,7	14,3	17,6	0,6	0,7
6.	8,00	5,5	7,4	8,7	17,3	0,5	0,5
7.	17,80	6,4	3,6	9,7	13,5	0,7	0,4
8.	240,0	-3,2	-9,9	0,0	0,0	0,6	0,8

3.6. Graphic presentation of measurement results

The obtained measurement results were presented in the following diagrams. In order to increase the diagram clarity a logarithmic scale was used. for the horizontal axis (target length)

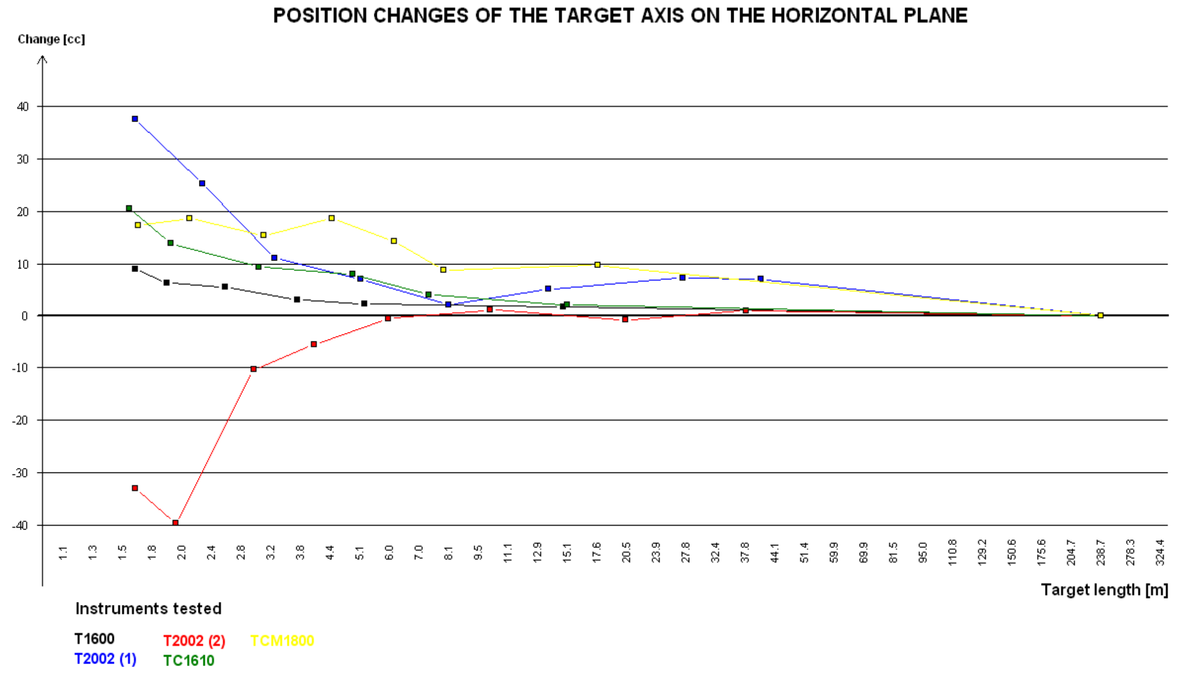

Fig. 2. Position changes of the target axis on the horizontal plane.

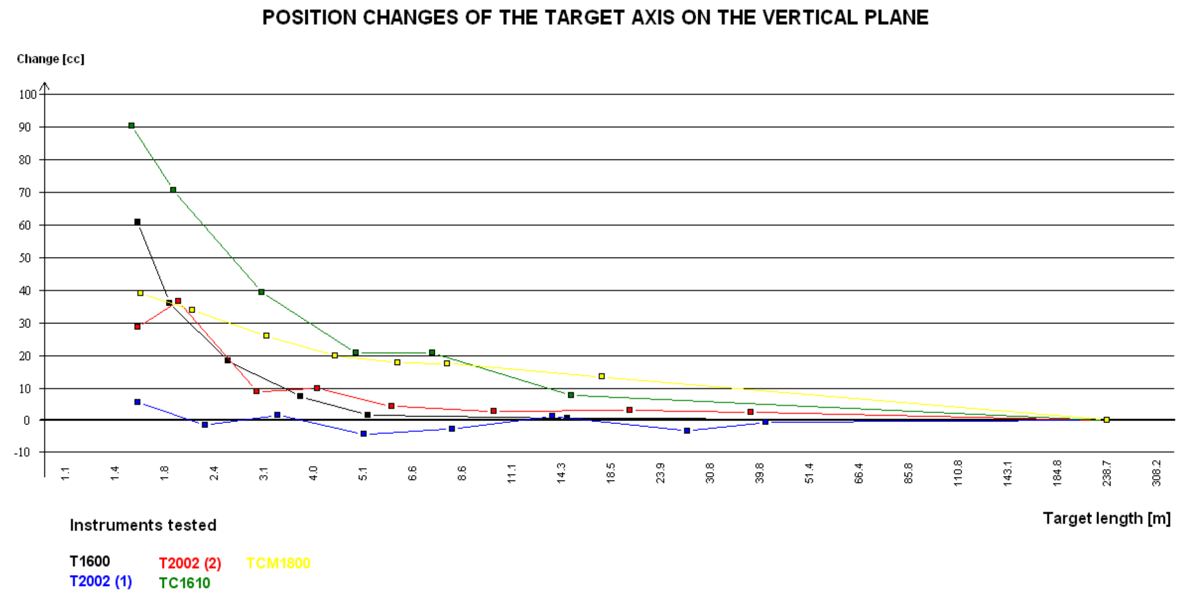

Fig. 3. Position changes of the target axis on the vertical plane.

4. SUMMING UP

The obtained measurement results show that for short targets of a few metres long, position changes of the target axis are considerable and even come close to 1^c (TC1610). Even in the case of the telescopes of precise T 2002 theodolites geared for close object measurements, target axis vacillations almost amount to 40^{cc}. The course of vertical changes in the target axis vacillations is quite distinctive/typical/unusual/interesting??

For all tested instruments the character of these changes was very similar. It is a phenomenon which is difficult to explain in a clear fashion. It should be also noted that the greatest changes take place with short targets up to about 10 m. Vacillations of the target axis above this length are considerably smaller and generally do not exceed 10^{cc}. Although target axis movements expressed in terms of angular units are significant , their influence on accurate location of a point position is slight and does not exceed (especially for the horizontal component) a few hundredths millimeters. In spite of this changes in the target axis should be taken into consideration in designing high precision angular measurements for small objects.

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