EXPERIMENTAL STATION USED FOR EMPIRICAL DETERMINATION OF THE ANGULAR ACCURACY OF THEODOLITES AND TOTAL-STATIONS

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Abstract

In a typical geodetic work are usually measured values of the angles and distance. Manufacturers try to minimize errors of these variable. In engineering surveying the precision of measurement must be high. To achieve this goal the instrument must be set in the vertical axis line of the instrument and signal. Also instruments should be tested to assess their accuracy. The article presents an experimental laboratory set used for empirical determination of the angular accuracy of total-stations. A purpose of the designed set was also to characterise a precision of measuring device and fixing its utilitarian range. As signals, it has been propose to use plummets made of wire with the perimeter of 0,04 mm. In this paper the author described the construction and operation of the instrument. The conducted experiments have shown high accuracy.

Keywords

geodetic geodetic angular measurements, geodetic equipment

1 INTRODUCTION

Instruments should be tested to assess their accuracy. Required accuracy of measurements performed in Poland, and their compliance with the international system of measurement, provide the technical requirements and measurement surveying in the relevant standards PN/ISO. The testing methods of surveying instruments are in International Standard 8322 "Building construction - Measuring instruments - Procedures for determining accuracy in use -- Part 4: Theodolites". Specifies testing procedures used to evaluate the precision in use of theodolites for measurement of horizontal and vertical angles in the gon and degree system. This standard has been revised by: ISO 17123-3:2001 Optics and optical instruments -- Field procedures for testing geodetic and surveying instruments -- Part 3: Theodolites. Field methods are described for determining and assessing the accuracy of theodolites and their equipment used in engineering and geodetic measurements.

This part of ISO 17123 specifies field procedures to be adopted when determining and evaluating the precision (repeatability) of theodolites and their ancillary equipment when used in building and surveying measurements. Primarily, these tests are intended to be field verifications of the suitability of a particular instrument for the immediate task at hand and to satisfy the requirements of other standards. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature. This part of ISO 17123 can be thought of as one of the first steps in the process of evaluating the uncertainty of a measurement (more specifically a measured). The uncertainty of a result of a measurement is dependent on a number of factors. These include among others: repeatability (precision), reproducibility (between day repeatability), traceability (an unbroken chain to national standards) and a thorough assessment of all possible error sources, as prescribed by the ISO Guide to the expression of uncertainty in measurement (GUM).These field procedures have been developed specifically for in situ applications without the need for special ancillary equipment and are purposefully designed to minimize atmospheric influences.

Procedure for determining the accuracy of the horizontal angle theodolite, used the following way:

1. Solid targets (4) should be established in the same horizontal plane like an instrument, at a distance from instrument 100 to 250 m (Fig. 1).
2. For simplified testing procedures we have one measurement cycle.
3. Each measurement cycle should consist of n = 3 series.

Then calculated the standard deviation (using average values). According to the guidelines of ISO test of survey instruments accuracy can be carried out according to the simplified or full. The position of the test subjects theodolites or total stations takes on a concrete pole having forced centering. Targets are perceived as permanent landmark with placed return reflectors. These points are a fixed part of the test database. The instruments should be tested on the possibility of occur errors of collimation and inclination. In order to improve these measurement procedures and the ability to release testing at any time of the year and in different weather conditions, was developed experimental station used for empirical determination of the angular accuracy of theodolites and total-stations. This set can be used inside, in a chamber conditions.

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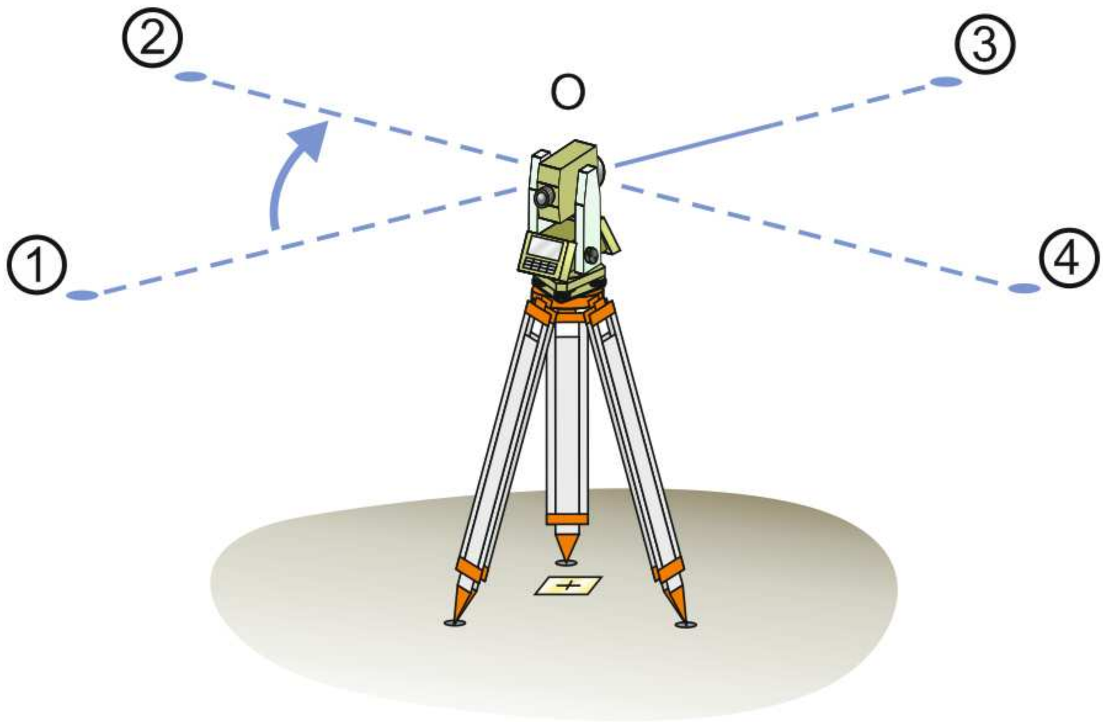

Fig. 1. *A station with aiming points*

2 CONSTRUCTION AND OPERATION OF A SET PLUMMET WITH NON-GLASS REFLECTOR

Under field conditions on the basis of a test to indicate the direction designated purposes, the known from the literature and brochures manufacturers of surveying equipment solutions shield and signal [7], [9], [10]. In order to perform the procedures described above in the laboratory room, as to the direction of the signaling is proposed to apply the vertical aiming shown in Figure 2. The prototype is shown in Figure 3.

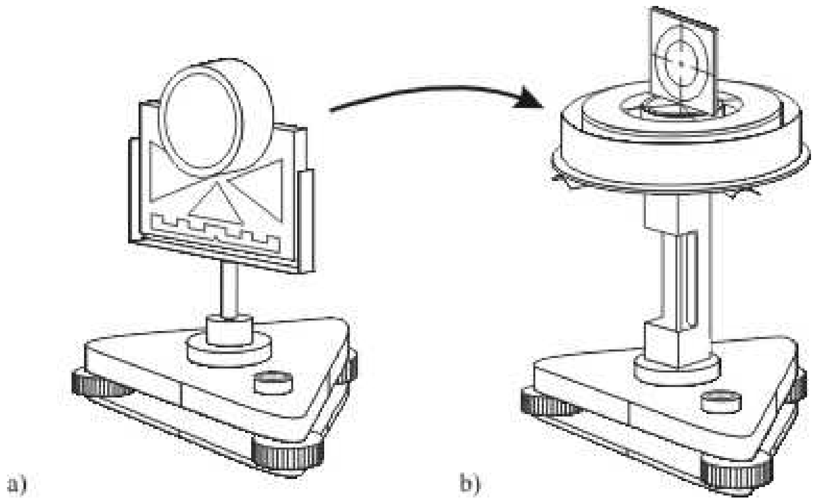

Fig. 2. *Signalling of aims by the accuracy examination of horizontal directions.*
a) version of the traditional applied aim
b) version of the proposed plummet (with non-glass reflector)
(source: Ćmielewski, 2007).

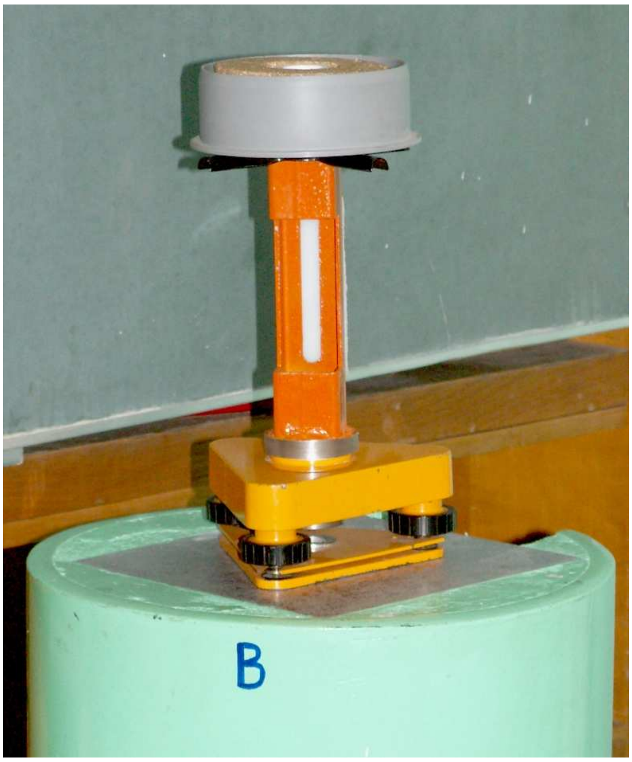

Fig. 3. *Finished device plummet (with non-glass reflector).*

The instrumental metrology issues, in the case of direct optical measurements, important is the correct response to the observer's eye to the phenomenon of coincidence and bisection. This phenomenon affects the accuracy of measurements [8]. Spacing grid lines of the crosshair in the survey instrument is included in the range from 3” to 5” [3]. Width to be chosen so that observed target short distance (order of a few meters) equated to approximately its angular width with the angular width of the cross threads (Figure 4).

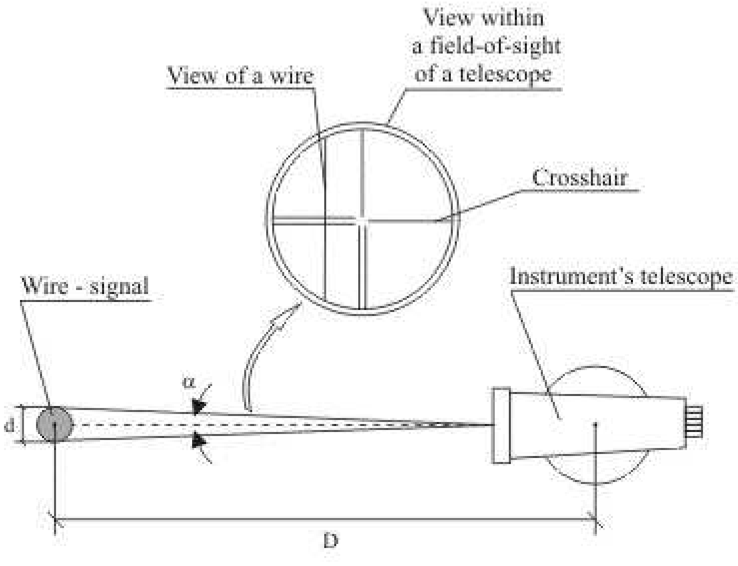

Fig. 4. *Application of the slight width aiming signal at telescope measurements (source: Ćmielewski, 2007).*

Figure 5 shows the effect of a full final targeting to the applied signal.

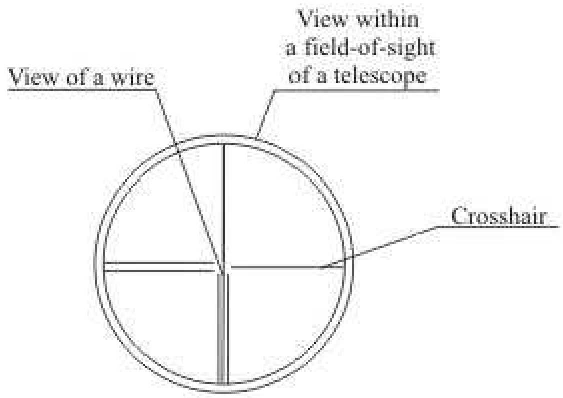

Fig. 5. *View of an aim point within a telescope range.*
Coincidence and bisection effect (source: Ćmielewski, 2007).

This objective can be wire with a diameter of 0.04 mm. The calculated angular value of the aim's width of the distance of observation is:

$$\alpha = \frac{d}{D} \cdot \rho'' \quad (1)$$

where:
d – the width aiming (diameter wire)
D – distances of observation.
The relationship described by the equation (1) allows the design distance to the position of the observation target. Table 1 shows the various options for the size of the adopted target - wire.

Distances of observation – D [m]	1,000	1,500	2,000	2,500	3,000
Angular value of the aim's width - α ["]	8,2	5,3	4,1	3,2	2,7

Tab. 1 Summary of angular values of the aim width – a wire with the perimeter of 0,04 mm for distances of observation

The detailed construction of the vertical aiming shown in Figure 6.

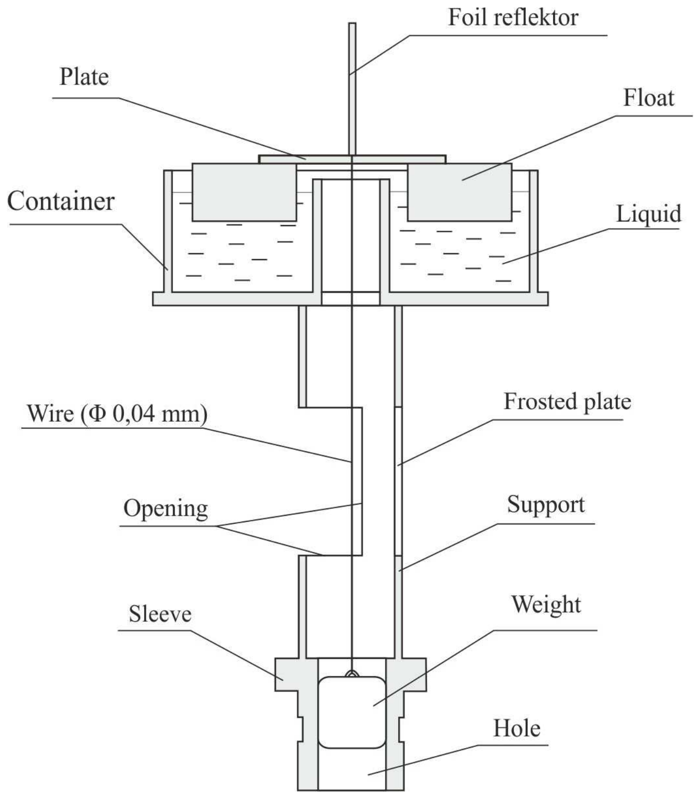

***Fig. 6**. Construction scheme of observational plummet in a cross-section (source: Ćmielewski, 2007).*

Observational plummet in their construction looks like a bracket. In the lower portion of it has sleeves. In the upper part is container filled with liquid. Float with foil reflector is placed in a liquid. To the bottom of the float is attached a wire of 0.04 mm diameter. It is suspended vertically in the bracket. In the lower part is provided with a weight. Weight is slidably mounted in the hole of the sleeve. Before measuring the tribrach must be leveled. Wire should be visible on the background matt. Matt can be illuminated, depending on the conditions of observations (Fig. 7).

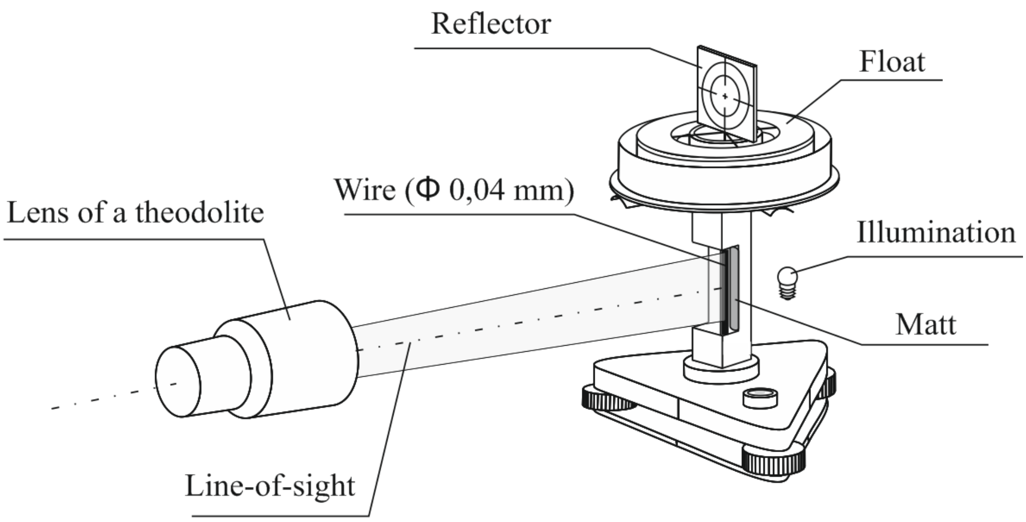

Fig. 7. *The example of aiming by the telescope of total-station at an observational plummet (source: Ćmielewski, 2007).*

Figure 8 shows proposals for the deployment a set of observational plummet in the laboratory.

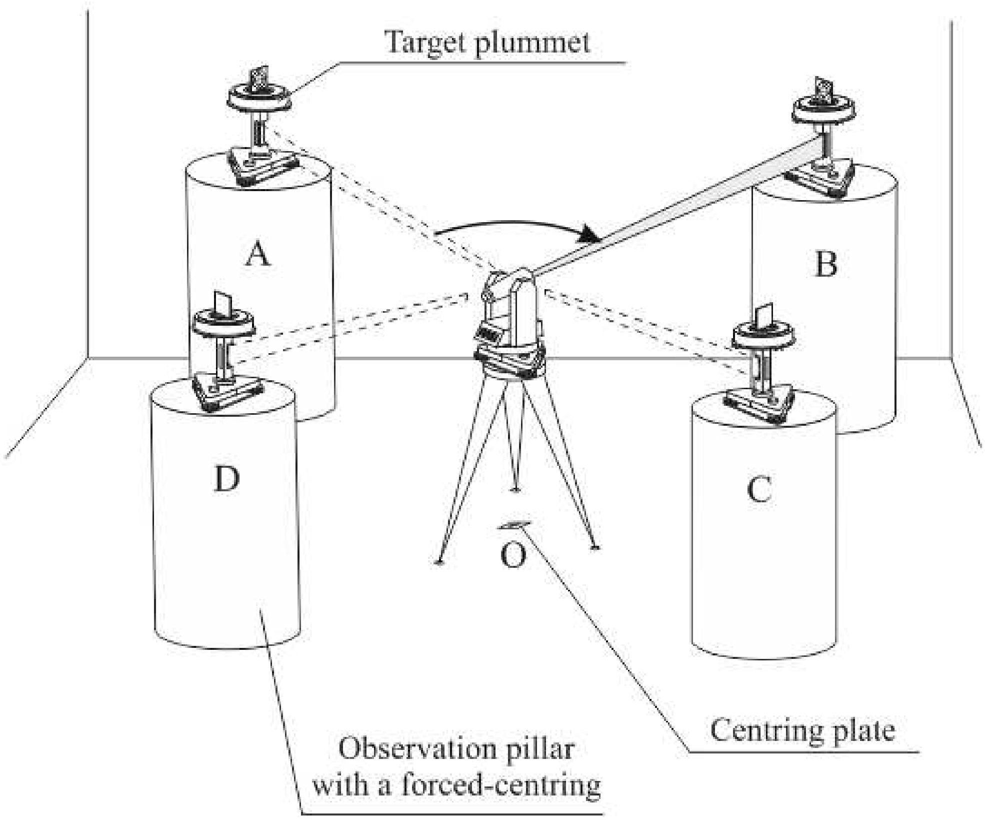

Fig. 8. *View of observational plummets and a theodolite at the examination process (source: Ćmielewski, 2007).*

Developed analytical measurement results provide the basis for determining the accuracy of the measurement of horizontal angles.

On this assumptions were performed further studies. To assess the accuracy of the instrument author conducted a series of observations consisting of an electronic tachymeter TC 407 Leica aiming at an observational plummet. At the center of the room was located measuring stand. Four points are indicated by observation discs evenly distributed on the walls of the room. Angle observations were made in three series. After each series shifted Limbo by 60 degrees. On the basis of readings were made calculations. Results of measurements and calculations are summarized in tables 2 – 3. On the Table 2 are results of measurements with use plummet with non-glass reflector. On the Table 3 are results of measurements with use fiber optic. The fiber optic signaling is shown in Figure 9.

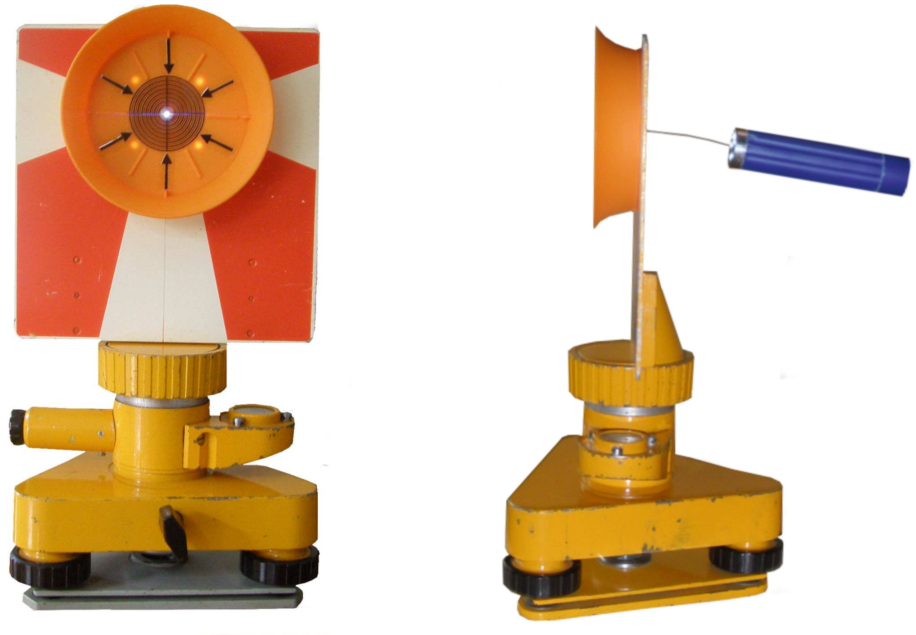

Fig. 9. *Fiber optic signaling (front view and side view).*

Stand	Target	I position Result		A B	Average		II position Result		A B	Average		Average of the two positions			Reduced directions			Average directions			Differences $d_{jk}=x_k - x_{j,k}$	Amendments $r_{j,k} = d_j - d_{j,k}$
		g	c	cc	c	cc	g	c	cc	c	cc	g	c	cc	g	c	cc	g	c	cc	c	c
1	2	3			4		5			6		7			8			9			10	11
A	1	332	12	95	12	87,5	132	12	20	12	25	332	12	56	0	00	00	0	00	00	0,0	0,0125
			12	80				12	30													
	2	42	68	85	68	87,5	242	67	80	67	75	42	68	32	110	55	75	110	56	30	0,55	-0,5375
			68	90				67	70													
	3	147	08	45	08	42,5	347	06	85	06	82,5	147	07	62	104	39	32	104	38	84	- 0,48	0,4925
			08	40				06	80													
	4	240	01	50	01	50	40	01	10	01	10	240	01	30	92	93	67	92	93	65	- 0,02	0,0325
			01	50				01	10													
End of the first series																				The sum of the differences	0,06	Σ r^2
																				Average	0,0125	0,533
A	1	392	12	50	12	55	192	13	55	13	65	392	13	10	0	00	00	0	00	00	0,0	-0,0475
			12	60				13	75													
	2	102	70	20	70	20	302	70	95	70	85	102	70	52,5	110	57	42	110	56	30	-1,12	1,072
			70	20				70	75													
	3	207	07	70	07	67,5	7	09	85	09	87,5	207	08	77,5	104	38	25	104	38	84	0,59	-0,637
			07	65				09	90													
	4	300	01	55	01	45	100	02	65	02	72,5	300	02	08,75	92	93	31	92	93	65	0,34	-0,295
			01	35				02	80													
End of the second series																				The sum of the differences	-0,19	Σ r^2
																				Average	-0,0475	1,644
A	1	52	13	05	13	07,5	252	13	70	13	80	52	13	43,75	0	00	00	0	00	00	00	0,035
			13	10				13	90													
	2	162	69	30	69	30	362	69	05	69	02,5	162	69	16,25	110	55	72	110	56	30	0,58	- 0,545
			69	30				69	00													
	3	267	08	20	08	07,5	67	08	20	08	17,5	267	08	12,5	104	38	96	104	38	84	-0,12	0,155
			07	95				08	15													
	4	360	02	00	02	10	160	02	20	02	10	360	08	10	92	93	97	92	93	65	-0,32	0,355
			02	20				02	00													
End of the third series																				The sum of the differences	0,14	Σ r^2
																				Average	0,035	0,448
																		Σ $r^2_{1,2,3}$				2,625
																		Standard deviation				**0,66**

***Tab. 2** Results of measurements with use plummet with non-glass reflector.*

Stand	Target	I position					II position					Average of the two positions			Reduced directions			Average directions			Differences $d_{jk}=x_k-x_{j,k}$	Amendments $r_{j,k}=d_j-d_{j,k}$
		Result		A B	Average		Result		A B	Average												
		g	c	cc	c	cc	g	c	cc	c	cc	g	c	cc	g	c	cc	g	c	cc	c	c
1	2	3			4		5			6		7			8			9			10	11
A	1	217	10	35	10	12	17	10	55	10	58	217	10	35	0	00	00	0	00	00	0,0	0,44
			09	90				10	60													
	2	320	46	65	46	90	120	37	50	47	42	320	47	16	103	36	81	103	37	68	0,87	-0,43
			47	15				47	35													
	3	17	72	20	72	22	217	72	85	72	70	17	72	46	200	62	11	200	62	84	0,73	-0,29
			72	25				72	55													
	4	119	01	90	02	02	319	01	20	01	15	119	01	59	301	91	24	301	91	42	0,18	0,26
			02	15				01	05													
End of the first series																				The sum of the differences	1,78	Σ r^2
																				Average	0,44	0,53
A	1	74	05	25	05	28	274	05	75	05	75	74	05	51	0	00	00	0	00	00	0,0	2,06
			05	30				05	75													
	2	177	41	25	41	38	377	41	75	41	68	177	41	53	103	36	02	103	37	68	1,66	0,40
			41	50				41	50													
	3	274	63	75	63	92	74	64	45	64	40	274	64	16	200	58	65	200	62	84	4,19	-2,13
			64	10				64	35													
	4	375	94	15	94	12	175	94	70	94	50	375	94	51	301	89	00	301	91	42	2,42	-0,36
			94	10				94	30													
End of the second series																				The sum of the differences	8,27	Σ r^2
																				Average	2,06	9,07
A	1	338	28	90	29	05	138	29	90	29	85	338	29	45	0	00	00	0	00	00	0,0	-3,36
			29	20				29	80													
	2	41	68	55	68	75	241	70	60	70	60	41	69	67	103	40	22	103	37	68	-2,54	-0,82
			69	00				70	60													
	3	138	96	55	96	75	338	97	75	97	70	138	97	23	200	67	78	200	62	84	-4,94	1,58
			96	95				97	65													
	4	240	22	65	22	82	40	23	35	24	10	240	23	46	301	94	01	301	91	42	-2,59	-0,77
			23	00				24	85													
End of the third series																				The sum of the differences	-10,07	Σ r^2
																				Average	-3,36	15,05
																		S $r^2_{1,2,3}$				24,65
																		Standard deviation				**2,02**

Tab. 3 *Results of measurements with use fiber optic.*

	Xi	Xsr	V	V*V	
1	297,2535	297,2533	-0,0002	8,26446E-09	
2	297,2538		-0,0005	8,26446E-09	
3	297,2526		0,0007	1,19008E-08	
4	297,2529		0,0004	3,64463E-08	
5	297,2535		-0,0002	8,26446E-11	
6	297,2537		-0,0004	8,26446E-11	
7	297,2530		0,0003	8,26446E-11	
8	297,2534		-0,0001	1,19008E-08	
9	297,2528		0,0005	8,26446E-09	
10	297,2538		-0,0005	9,55372E-08	
11	297,2536		-0,0003	8,26446E-09	**m_K**
				1,89091E-07	**0,0001**

Tab. 4 *Results of measurements and calculate direction error (TC407).*

3 SUMMARY AND CONCLUSIONS

The proposed laboratory test base can complement measurement techniques and procedures stored in PN / ISO, persists at the same time the accuracy of measurement error direction and angle. The above consideration clarified on the basis of experimental. Measurement error less than 1^{cc} obtained for a distance of 2 m. Presented target is easy to use, simple in construction and is small. Can also be used on limited size of engineering sites that require observation angle with good accuracy [1], [6]. Natural goal of wire with a small width allows for the elimination of errors occurring in the optical collimators. Applicable goals at equal distances from the position allows to reduce to a minimum the errors related to the changing with a focusing during measurement. Observations made with the use of the proposed vertical aiming should take place in conditions of limited vibration because they affect both the tested instrument and vertical aiming.

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