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DETERMINATION OF PERMANENT CORRECTIONS OF BALL REFLECTORS

Today, there are many manufacturers of triple-prism, spherical reflectors with different mechanical characteristics. That is why there is a problem of matching the signal reflection center with the geometric one. The purpose of this work is to evaluate the methods of determining permanent corrections of electronic tacheometers, ball reflectors and to develop recommendations for their use. Method. To determine the instrument correction, a displacement interferometer is used. It contains a two-frequency He-Ne laser with a wavelength of l = 0.63 μm (red range). The study compared the results of length measurements by an interferometer and an electronic total station with a ball reflector. This allowed determining the instrument correction. The research defined the constant correction of reflectors and total stations on the phase section of the field base using the method of created linear observations. Results. Experimental studies of ball reflectors of various manufacturers and Leica electronic tacheometers were conducted. The determination of constant instrument corrections of the total station and reflector using the displacement interferometer can be performed with an accuracy of 0.1 mm. This significantly depends on the accuracy of measuring lines with the total station. The use of ball reflectors with a built-in triple prism allows significant increase of distance measurement accuracy by reducing centering errors, considering the constant instrument correction (up to 0.4 mm for Leica 1201 total stations). Scientific novelty. The methods of determining permanent corrections of ball reflectors and total stations were investigated. The proposed method determines the measurement interval length with the exception of systematic constant correction of the electronic total station and reflector. Practical relevance. The use of ball reflectors is recommended for quick and unambiguous installation at points, convenience of their use for monitoring observations, as well as for increasing the accuracy of linear measurements due to the reduction of centering errors. In order to achieve high-precision measurements of short lines, it is recommended, according to the performed studies, to carefully determine the constant correction of the total station and ball prisms. This makes it possible to increase the accuracy of line measurements at least three times compared to the declared accuracy of the total station manufacturer.

Key words: permanent instrument correction, electronic tacheometers, ball reflector, triple-prism, interferometer.

Introduction

The accuracy of measuring lines depends on the accuracy of determining corrections in the measurement results. Modern electronic tacheometers are equipped with high-precision laser measuring systems. Design features of these systems in geodetic devices are associated with the occurrence of permanent corrections. The appearance of ball reflectors with built-in triple-prisms in geodetic production led to an increase in the accuracy of measuring lines due to the reduction of centering errors of sighting targets and the unequivocalness of their installation in magnetic stands and holes.

There is an actual problem of using ball reflectors for measuring lines in special conditions, when the observed points are difficult to access. It is necessary to determine the constant instrument correction of ball reflectors. In addition to permanent corrections of the electronic tacheometers themselves, the measurement results include permanent corrections of reflectors. The total permanent correction to line measurements for each tacheometer and reflector set is determined individually.

Goal

Evaluate methods for determining permanent corrections of electronic tacheometers and reflectors and develop recommendations for their application to increase the accuracy of linear measurements.

Analysis of previous research

The most complete studies of instrument and cycle correction are usually performed on a linear basis. Reference intervals between base points must be known with precision [Instruction] $m_D =$ $= 0.3\,mm(a + b \times Skm)$.

Let us calculate the permissible errors of the phase section, on which the instrument corrections are usually determined. According to the instructions for topographic electronic tacheometers, for which $a = 2\,mm$, we will get $m_D = 0.6\,mm$. For more precise definitions $a = 0.5 - 1\,mm$, then $m_D = 0.1 - 0.33\,mm$. The base points are tubular signs laid at a depth of approximately 2.5 m. In the upper part of the sign there is a metal platform with a hole for forced centering of the device and reflectors. The centering error on other bases exceeds 0.05 mm with the use of special devices or screws [Standard screw. Stalemate. 145153]. Creating such a base is quite expensive. Accurate measuring reference intervals is also difficult and costly.

There is a known method of determining the permanent correction of distance measurement in all combinations on such bases [Kostetska, Bletskan, 2011]. The authors improved the method, using the Gaussian method and found the minimum of the function for determining the errors of the measured distances [Lysko, Mykhailyshyn, 2021]. In our previous works, we proposed a method of determining the reference segments of the basis by the linear-angular method [Litynskyi et al., 2015]. Also, in the user instructions for electronic tacheometers, manufacturers offer a way to determine the instrument correction by measuring the entire segment and its two parts. The work [Pokotylo, Korliatovych, & Vovk, 2020] proposed a technique for determining meter intervals of the base using a control meter and a camera, which increases the accuracy of counting. Such methods of determining permanent reflectors are used in engineering and geodetic works. In the works during the installation of the equipment in the design position, there is a need for additional studies of electronic tachometers. For example, the work [Burak, & Mykhailyshyn, 2018] developed the method of using electronic tachometers to determine the parameters of under-crane tracks. In the work [Vivat, et al., 2018] reviewed the methods of determining the geometric parameters of technological equipment and suggested the use of electronic tacheometers with additional accessories to increase the accuracy of measurements. For quick coordinate reference and monitoring stationary and moving targets [Periy, Vankevich, & Samara, 2021] it is proposed to perform observations on ball reflectors with magnetic stands. The work [Lackner & Lienhart, 2016] investigated the accuracy of electronic tacheometers with the help of an interferometer. It presented the possibility of increasing the measurement accuracy using special equipment. Manufacturers of industrial equipment suggest utilizing ball reflectors which increase the measurement accuracy of electronic tacheometers by three times [Schweitzer, & Schwieger, 2011]. In the works [Werner, Petrakov & Shuplietsov, 2018; Lienhart, 2017] suggest using laser trackers and modern high-precision multistations [Leica Nova TS60] for high-precision measurements in industry. Auxiliary equipment for increasing the accuracy of measurement by electronic tacheometers is researched in the work [Tserklevych, et al., 2022].

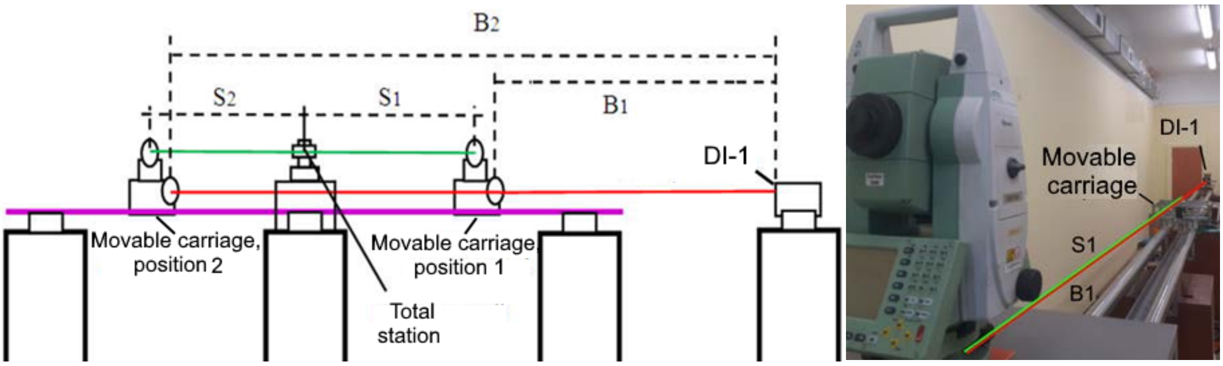
In this article, we performed a study of different diameter ball reflectors with different permanent corrections. The studies were carried out according to a number of methods using various devices to compare the accuracy of determining the instrument correction. We developed a method of increasing the accuracy of measuring distances, thus, determining coordinates by electronic tacheometers using ball reflectors. The studies were performed on a linear basis and verified with an interferometer.

Methodology

Currently, there are several manufacturers of ball reflectors on the world market. And although their mechanical characteristics is almost the same (spherical accuracy, alignment of the center), they have different determination of coordinates by measurements. We examined seven ball reflectors from different manufacturers (Fig. 1).

Determination of the instrument correction was carried out using a displacement interferometer according to the method described in [Method of determination of the instrument correction Pat. 120949]. It involves movement measurement between two positions of the carriage with a reflector by an interferometer and measurement of the reference lines to the reflector by a total station (Fig. 2). The DI-1 interferometer contains a dual-frequency He-Ne laser. It emits an optical beam with a wavelength l of approximately 0.63 μm (red range), consisting of two optical oscillations formed due to the splitting of the Ne line in a magnetic field (the Zeeman effect). These oscillations have a mutually perpendicular polarization located in the horizontal and vertical planes. When the reflector moves towards the interferometer, the frequency of passage of the information channel pulses increases in relation to the frequency of passage of the reference channel pulses. When it moves in the opposite direction, the frequency decreases. This change determines the speed and direction of the reflector's movement. After moving the reflector to the side of the interferometer, the number of pulses passed in the information channel turns out to be greater than in the reference channel. And after moving in the opposite direction, it is less than in the reference channel. The magnitude and sign of this difference in the number of pulses unambiguously define the amount and direction of movement of the reflector with an accuracy of 0.005 mm.

Fig. 1. Investigated ball reflectors



a *b*

Fig. 2. Scheme for determining the correction of reflectors (a), measurement process (b)

To determine permanent reflectors in the field, you can apply the method of line measurements.

On a flat area, the angle of inclination of which does not exceed 2°, choose a line 20–30 m long. Install the device at one end of the line, then put a reflector on a tripod at another end.

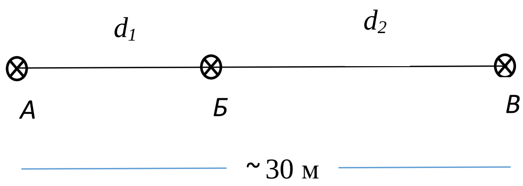


Fig. 3. Scheme of created linear measurements of segments

An additional tripod with a reflector is installed in the target with an accuracy of 1 mm, approximately in the middle (Fig. 3).

Let us assume that the true values of the horizontal projections of the lines are known АБ=d_1 and БВ=d_2.

From the installation of the device at point A, two lines are measured with an unknown constant correction K of the rangefinder and the reflector:

$$d_{АБ} = d_1 + K, \quad (1)$$

$$d_{АВ} = d_1 + d_2 + K. \quad (2)$$

Install the device at point B. Measure two more lines $d_{БА}$ and $d_{БВ}$. At the same time, it is important to control the reverse horizontal projection of the first line $d_{АБ}$ and the angle of creation:

$$d_{БА} = d_1 + K, \quad (3)$$

$$d_{БВ} = d_2 + K. \quad (4)$$

Let us add (3) and (4) and get:

$$d_{БА} + d_{БВ} = d_1 + d_2 + 2K. \quad (5)$$

Subtract (2) from (5) and get the value of the constant correction K of the rangefinder and reflector:

$$d_{БА} + d_{БВ} - d_{АВ} = \\ = d_1 + d_2 + 2K - (d_1 + d_2 + K) = K_3. \quad (6)$$

To control the determination of the permanent correction, measure these two lines from point B.

Then the permanent correction is found three times. To do this, subtract (1) from (2) and get the true value d_2:

$$d_{ВБ} = d_2 + K, \quad (7)$$

$$d_{ВА} = d_1 + d_2 + K, \quad (8)$$

$$d_2 = d_{АВ} - d_{АБ} = d_1 + d_2 + K - (d_1 + K), \quad (9)$$

$$K_1 = d_{ВБ} - d_2. \quad (10)$$

Similarly, from the point $B - d_1$:

$$d_1 = d_{ВА} - d_{ВБ} = d_1 + d_2 + K - (d_2 + K), \quad (11)$$

$$K_2 = d_{АБ} - d_1. \quad (12)$$

The third value of the constant is found from equation (5) by formula (6). Based on the results of six-line measurements, three values of the instrument correction for the corresponding reflector are determined.

Results

Determination of the instrument correction was performed with the help of an interferometer of displacements in three steps using a patented method [Method of determination of the instrument correction... Pat. 120949].

Table 1 shows the obtained results of the constants determined by the interferometer and electronic total station Leica 1201. This corresponds to the accuracy of measuring lines according to the regression equation $m_D = 1mm + + 1mm \cdot D \cdot 10^{-6}$, with the use of ball reflectors of various design sizes.

Table 1

Determination of permanent corrections of Leica 1201 electronic total station and ball reflectors using an interferometer in 2022

No.	Ball reflector	Diameter, mm	Constant, mm	CSD, mm
1	П12-1	32	-5.53	0.06
2	П12-2	32	-5.44	0.03
3	П25-1	32	-22.82	0.06
4	П25-б	32	-22.67	0.05
5	ПNo.196	45	-16.63	0.06
6	ПNo.162	38	-17.49	0.06
7	Пб/No.	45	-13.93	0.09
			av.	**0.06**

The corrected standard deviation (CSD) of the constant correction determination of the total station and reflector was 0.06 mm. This indicates high-precision measurements made by the electronic total station. Somewhat worse results were obtained on the Pb/No. ball reflector which had a poorly made spherical surface of the ball. Table 2 shows the results of constant corrections determined by an interferometer and a Leica 1205 electronic total station. This corresponds to the accuracy of measuring lines according to the regression equation $m_D = 2 \text{ mm} + +2 \text{ mm} \cdot D \cdot 10^{-6}$, with the use of ball reflectors of various design sizes.

Comparing the results of recent corrections with different tacheometers, it is necessary to consider the systematic value for each day. The systematic error of determining the constants for different tacheometers means a constructive change in their constants.

This *av.*=−0.24 indicates discrepancies in the constants of the devices themselves, since the measurements were performed on the same reflectors and according to the same observation method. The results of the comparison are shown in Table 3.

Table 2

Determination of permanent corrections of Leica 1205 electronic total station and ball reflector s using an interferometer in 2021

No.	Ball reflector	Diameter, mm	Constant, mm	CSD, mm
1	П12-1	32	-5.31	0.07
2	П12-2	32	-5.19	0.04
3	П25-1	32	-22.62	0.04
4	П25-б	32	-22.49	0.05
5	ПNo.196	45	-16.34	0.02
6	ПNo.162	38	-17.21	0.03
7	Пб/No.	45	-13.67	0.08
			av.	**0.05**

Table 3

Comparison of Leica 1201 and Leica 1205 electronic total station permanent corrections and ball reflectors using an interferometer in 2022

No.	Ball reflector	Diameter, mm	Constant Leica 1201, mm	Constant Leica 1205, mm	Difference Leica 1201 and Leica 1205, mm
1	П12-1	32	-5.53	-5.31	-0.22
2	П12-2	32	-5.44	-5.19	-0.25
3	П25-1	32	-22.82	-22.62	-0.20
4	П25-б	32	-22.67	-22.49	-0.18
5	ПNo.196	45	-16.63	-16.34	-0.29
6	ПNo.162	38	-17.49	-17.21	-0.28
7	Пб/No.	45	-13.93	-13.67	-0.26
				av.	-0.24
				CSD	0.04

In 2020, experimental measurements were conducted to determine the permanent corrections of four spherical reflectors on the phase section of the linear basis of the LNAU in Dublyany.

For this, measurements of horizontal projections of lines from five points of the linear basis were performed alternately. They were carried out in three rounds by a Leica 1201 robotic electronic total station using the ATR function of automatic targeting at the maximum of the reflected signal.

Table 4 demonstrates the results of processing the determination of constant corrections, their accuracy assessment and comparison with the determined corrections using an interferometer.

The analysis of Table 4 indicates a doubling of the adjusted standard deviation of the constant correction definition. This is explained by the triple measurement of lines to determine the constant on a linear basis compared to the double measurement in the determination using an interferometer.

The analysis of the created line measurements results allows us to introduce a method of determining the interval length, excluding the systematic constant correction of the electronic total station and reflector. Using equations (9) and (11), we determined the intervals of the bases measured by the electronic total station with the exception of the constant ones by four reflectors at different settings of the instrument at marks 1, 3, 8, 13 and 15. The results of the obtained intervals are shown in table 5.

Table 4

Comparison of Leica 1201 electronic total station permanent corrections and ball reflectors using a linear basis in 2020

No.	Ball reflector	Diameter, mm	Constant Leica 1201 and interferometer, mm	Permanent Leica 1201 and linear basis, mm	CSD determination of the constant on a linear basis, mm	The difference between the constants determined by the interferometer and the linear basis, mm
1	П12-1	32	-5.53	-5.77	0.22	0.24
2	П12-2	32	-5.44	-5.61	0.20	0.17
3	П25-1	32	-22.82	-22.93	0.19	0.11
4	П25-б	32	-22.67	-22.90	0.20	0.23
				av.	0.20	0.19
				CSD	0.01	0.06

Table 5

Comparison of the intervals measured by the electronic total station Leica 1201 on ball reflectors considering the constants of the device with the intervals of the linear basis in 2020

No. definitions	Intervals between pipe marks of the linear basis, m			
	1–3	3–8	8–13	13–15
1	9.99260	5.00032	4.99992	10.01063
2	9.99260	5.00047	4.99970	10.01063
3	9.99277	5.00043	4.99983	10.01067
4	9.99263	5.00032	4.99995	10.01062
5	9.99280	5.00047	4.99962	10.01082
6	9.99295	5.00045	4.99963	10.01067
7	9.99275	5.00057	4.99968	10.01063
8	9.99277	5.00057	4.99968	10.01057
9	9.99220	5.00073	4.99965	10.01057
10	9.99303	5.00037	4.99972	10.01050
11	9.99288	5.00078	4.99943	10.01062
12	9.99277	5.00058	4.99967	10.01055
av.	**9.99273**	**5.00050**	**4.99971**	**10.01062**
CSD	**0.00021**	**0.00015**	**0.00014**	**0.00008**
Basis	**9.99315**	**5.00041**	**5.00002**	**10.01024**
Difference (basis-av)	**0.00042**	**-0.00009**	**0.00031**	**-0.00038**

The magnitudes of the differences (basis-average) fully correspond to the accuracy of determining the five-meter intervals of the linear basis with the help of a compared control meter with the use of photo-fixation in the countdown.

Scientific novelty and practical significance

The methods of determining permanent corrections of ball reflectors and total stations were investigated. The study introduced the method of determining the length of measurement intervals, excluding the systematic constant correction of the electronic total station and reflector.

The use of ball reflectors is recommended for quick and unambiguous installation at points, convenience of their use for monitoring observations, as well as for increasing the accuracy of linear measurements due to the reduction of centering errors. In order to achieve high-precision measurements of short lines, it is recommended to carefully determine the constant correction of the total station and ball reflectors. This makes it possible to increase the accuracy of line measurements at least three times compared to the declared accuracy of the total station manufacturer.

Conclusions

1. The use of spherical reflectors with a built-in triple prism allows significant increase in accuracy of measuring distances by reducing centering errors, considering the constant instrument correction (for Leica 1201 total stations up to 0.4 mm).
2. Measurements of short intervals by Leica 1201 and Leica 1205 total stations on tripelprism reflectors are the same in accuracy, although they have different regression equations stated by the manufacturer.
3. Determination of constant instrument corrections of the total station and reflector with the use of a displacement interferometer can be performed with an accuracy of 0.1 mm, which significantly depends on the accuracy of measuring lines with the total station.

REFERENCES

Burak, K. O., & Mykhailyshyn, V. P. (2018). The method of determining the geometric parameters of circular crane tracks. Scientific bulletin of NLTU of Ukraine, 28(5), 130–134. URL: https://doi.org/10.15421/40280527.

Instructions for topographic surveying at scales of 1:5000, 1:2000, 1:1000 and 1:500. (1999). Kyiv, GUGK.

Kostecka, Ya., & Bletskan, V. (2011). Elaboration of the results of the study of the instrument correction of total stations using the measurement of line segments in all combinations. *Geodesy and Geodynamics,* II (22), 109–111.

Lackner, S., & Lienhart, W. (2016, March). Impact of prism type and prism orientation on the accuracy of automated total station measurements. In *Proc. 3rd Joint International Symposium on Deformation Monitoring*.

Leica Nova TS60 – World’s most accurate total station. URL: https://leica-geosystems.com/products/total-stations/robotic-total-stations/leica-nova-ts60.

Lienhart, W. (2017). Geotechnical monitoring using total stations and laser scanners: critical aspects and solutions. *Journal of civil structural health monitoring*, 7, 315–324. URL: https://doi.org/10.1007/s13349-017-0228-5.

Litynskyi, V., Vivat, A., & Litynskyi, S. (2015). The method of measurement of the Model base of the 2nd category for the calibration of electronic tacheometers. Geodesy, cartography and aerial photography, 81, 59–65. URL: https://doi.org/10.23939/istcgcap2015.01.059.

Lysko, B. O., & Mykhailyshyn, V. P. (2021). Determination of the constant correction of electronic rangefinders by methods of nonlinear programming. Scientific bulletin of NLTU of Ukraine, 31(2), 98–102. URL: https://orcid.org/0000-0002-2525-1557.

Periy, P., Vankevich, P., & Samara, S. (2021). Application of ball reflectors for coordination and monitoring of moving and stationary objects. Materials of the International Scientific and Technical Conference “Geoforum-2021”. URL: http://zgt.com.ua/mntk-geoforum-3-2-2-2-2/.

Petrakov, Y., & Shuplietsov, D. (2018). Accuracy control of contour milling on CNC machines. URL: https://doi.org/10.20535/25211943.2018.83.132223.

Pokotylo, I., Korliatovych, T., & Vovk, A. (2020). Geodetic monitoring of meter intervals of the Berezhany basis. In International Conference of Young Professionals “GeoTerrace-2020” (Vol. 2020, No. 1, pp. 1–5). EAGE Publications BV. URL: https://doi.org/10.3997/2214-4609.20205747.

Schweitzer, J., & Schwieger, V. (2011). Modeling of quality for engineering geodesy processes in civil engineering. URL: https://doi.org/10.1515/jag.2011.002.

Self-tapping screw for fastening geodetic devices with centering plates of pipe marks: pat. 145153 Ukraine: 2020 No. 145153; statement 06/09/2020; published 25.11.2020.

The method of determining the instrument correction using a laser interferometer: patent. 120949 Ukraine: 2006. No. a201706967; statement 07/03/2017; published 10.03.2020.

Tserklevych, A., Vivat, A., & Petrov, S. (2022). Engineering solutions for increasing the accuracy of geodesic measurements by total stations. *Geodesy, Cartography, and Aerial Photography,* 96, 58–69. URL: https://doi.org/10.23939/istcgcap2022.96.058.

Vivat, A., Tserklevych, A., & Smirnova, O. (2018). A study of devices used for geometric parameter measurement of engineering building construction. *Geodesy, Cartography and Aerial Photography*: 87, 21–29. URL: https://doi.org/10.23939/istcgcap2018. 01.021.

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ВИЗНАЧЕННЯ ПОСТІЙНИХ ПОПРАВОК КУЛЬКОВИХ ВІДБИВАЧІВ

На сьогодні існує багато виробників відбивачів трипельпризмових, кулькових, механічні характеристики яких різняться, саме тому існує проблема суміщення центру відбивання сигналу із їх геометричним центром. Мета цієї роботи – оцінити методи визначення постійних поправок електронних тахеометрів, кулькових відбивачів та розробити рекомендації щодо їх застосування. Методика. Для визначення приладової поправки застосовано інтерферометр переміщень, який містить двочастотний He-Ne лазер з довжиною хвилі λ = 0,63 мкм (червоний діапазон). Порівняння результатів вимірювань довжин інтерферометром та електронним тахеометром до кулькового відбивача дало можливість визначити приладову поправку. Виконано дослідження визначення постійної поправки відбивачів і тахеометра на фазовій ділянці польового базиса із використанням методики створних лінійних спостережень. Результати. Виконано експериментальні дослідження кулькових відбивачів різних виробників та електронних тахеометрів Leica. Показано, що визначення постійних приладових поправок тахеометра та відбивача із застосуванням інтерферометра переміщень можна виконати з точністю 0,1 мм, яка значно залежить від точності вимірювання ліній тахеометром. Застосування кулькових відбивачів з вмонтованою трипельпризмою дає змогу значно підвищити точність визначення вимірювання віддалей унаслідок зменшення похибок центрування із врахуванням постійної приладової поправки (для тахеометрів Leica 1201 до 0,4 мм). Наукова новизна. Досліджено методи визначення постійних поправок кулькових відбивачів та тахеометрів. Запропоновано методику визначення довжин вимірювальних інтервалів із виключенням систематичної постійної поправки електронного тахеометра і відбивача. Практична значущість. Рекомендовано застосування кулькових відбивачів для швидкого та однозначного установлення на пунктах, зручності їх використання для моніторингових спостережень, а також для підвищення точності лінійних вимірювань зменшенням похибок центрування. Для досягнення високоточних вимірювань коротких ліній рекомендовано, відповідно до виконаних досліджень, ретельно визначити постійну поправку тахеометра та кулькових призм, це дає можливість підвищити точність виміру ліній принаймні втричі, порівняно із заявленою точністю виробником тахеометрів.

Ключові слова: постійна приладова поправка, електронний тахеометр, кульковий відбивач, трипельпризма, інтерферометр.

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