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Development Research Methodology Elastic Deformation Total Station

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Abstract: The results of experimental measurements with use of a electronic tacheometer (total station) proving the presence of elastic deformations of the device support caused by imbalance of the moving parts (the alidade). Deformations lead to errors in a measurement of horizontal angles. The study presents the research methods of the fixed part of a electronic tacheometer as well as ways to increase in several times the accuracy of determining the azimuth and vertical deformation of the support. For measurements use a special device with two optical mirrors located vertically at an angle of 90° to each other and fixed to the stationary part of the electronic tacheometer below the alidade but above the support. If there are no elastic deformations, then upon rotating the alidade of the horizontal circle of the tested electronic tacheometer, the device must be static. If elastic deformations exist, the device with mirrors may turn around the vertical axis (azimuthal rotations) that can be registered by other electronic tacheometers (measuring tacheometers). These turns lead to errors in measuring horizontal angles.

Key words: Electronic tacheometer, mirror, elastic deformations, deviation curves, research, alidade

INTRODUCTION

Assurance of measurement's accuracy for geodetic devices is an important task of manufacturers and companies on service of electro-optical angle measuring instruments. Carrying out a comprehensive study of electronic tacheometers (Nikonov and Rakhymberdina, 2013; Bespalov and Miroshnichenko, 2009; Bakharev *et al*., 2005) is important to ensure accuracy which should be provided by an instrument. Upon that, such tests should be performed both in the laboratory and in production conditions (Ustavich and Nikonov, 2015; Nikonov, 2015; Vshivkova, 2011; Zheltko *et al*., 2015).

Some specialists have doubts about the results represented in some studies (Gura *et al*., 2011; Gura *et al*., 2011; Zheltko *et al*., 2014a, b; Gura *et al*., 2011a-c) on research of angle errors for different harmonics of a electronic tacheometer horizontal circle and assumptions that some of them are caused by elastic deformations. Although, Ustavich and Nikonov (2015) has presented studies made many years ago on gyrocompasses 15SH29 and optical theodolites RT-02M and T2 indicating presence of errors caused by elastic deformations, evidences of such errors in modern electronic tacheometers is possibly not enough. In connection with this technique, etc. In this regard, a technique for additional studies has been developed.

MATERIALS AND METHODS

Description of the study technique: The procedure is provided for use of the device with a mirror. The device is fixed to the stationary part of the instrument, for example, below the horizontal circle alidade, but above the support. When the alidade of the tested electronic tacheometer rotates the instrument should be fixed device if there are no elastic deformations. When elastic deformations are present, the device with the mirror may turn around its vertical axis (azimuthal rotations); those rotations can be fixed by another electronic tacheometer (measuring). Those rotations lead to errors in the measurement of horizontal angles.

Another component of elastic deformations, turns around the horizontal axis (twists of the device) while rotating the unbalanced alidade of the horizontal circle, have been found in the studies carried out previously (Gura *et al*., 2011; Zheltko *et al*., 2013) and the amplitude of the oscillations of some electronic tacheometers reaches over 0.5'.

Possible rotations of the mirror were registered by the electronic tacheometer, in which telescope a sighting target fixed to a room wall is visible through the mirror (Fig. 1).

During tests, we have aimed a electronic tacheometer on the sighting target at different positions of the tested electronic tacheometer alidade, took readings; we also

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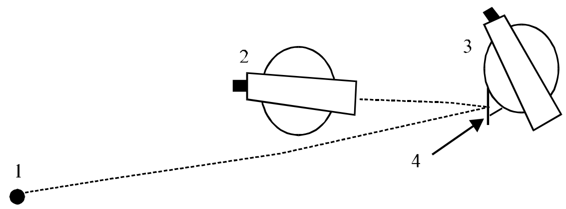

Fig. 1: Instrument arrangement diagram; 1: sighting target; 2: measuring total station; 3: tested total station; 4: mirror

have calculated deviations of readings from mean value that will be a function of errors caused by elastic deformations. At the same time, deviations, except for a useful result, will also include errors upon aiming the sighting target and readings along circles. This factor reduces the accuracy of the proposed testing.

Ways to reduce the effect of test errors: However, it is possible to reduce significantly the effect of those testing errors in two ways.

Firstly, it is necessary to place the measuring instrument and the sighting target with respect to the mirror in such a manner that the factor should be:

$$k_1 = \frac{\Delta\varphi}{\Delta\alpha} \quad (1)$$

where, $\Delta\varphi$ is change the reading along a Horizontal (HA) or Vertical Angle (VA) with a small mirror turn $\Delta\alpha$, respectively the vertical or horizontal (coinciding with the mirror plane) axes to be maximum. The formulas for k_1 have been deduced:

- For the horizontal circle:

$$k_1 = \frac{2b}{a+b} \quad (2)$$

- For the vertical circle:

$$k_1 = \frac{2b \cdot \cos\gamma}{a+b} \quad (3)$$

Where

a, b = Distances between the mirror and the electronic tacheometer, between the mirror and sighting target, respectively

γ = A horizontal angle between the sighting axis of the measuring electronic tacheometer and the perpendicular to the mirror

From Eq. 2 and 3 it is clear that the coefficient k_1 when $b >> a$ and $\gamma \approx 0°$ can reach 2. This means that accuracy of experimental measurements can be increased almost in two times due to the fact, for example, that by turning the mirror by 1", reading along the circle of the measuring electronic tacheometer changes by 2".

Secondly, it is possible to improve the measurement accuracy by additional fixation of a load in the right place of the alidade thus several times increasing normal torque. Upon that, it is necessary to measure or calculate the factor:

$$k_2 = \frac{M}{M_0} \quad (4)$$

where, M and M_0 are moments of force caused by an eccentricity of the alidade with additional weight and without it, respectively. Both moment vectors are horizontal and must match in the direction.

Method for accurate measurement of force moment vector: The researchers have developed a method to accurately measure the force moment vector M_0 generated by an eccentricity of the alidade without disassembling the device. Using the first proposed method, the additional load is calculated, selected and attached to the alidade so that the coefficient k_2 was in the range of 2-5. Upon that, it is reasonably assumed that the possible elastic deformations of the electronic tacheometer parts are proportional to the moment of force.

As a result of using these two approaches, fluctuations of readings measured along circles and caused to the elastic deformation will be amplified in $k_1 \cdot k_2$ times that is equivalent to a reduction of harmful errors in testing in this number of times.

The measurements were made immediately in both circles: horizontal and vertical. Aiming to the sighting target was made with use of crosshairs.

When testing the electronic tacheometer on a tripod with the device fixed above the support, it is impossible to establish where deformations occur in the electronic tacheometer or tripod. In order to resolve this uncertainty, similar studies were carried out for another position of the device with a mirror between the support and the tripod head. Then, subtracting results of the second testing from the corresponding figures of the first one, we obtain the deformations of the device parts only. Tripod deformations will be absent in them.

It is important for the research that the sighting axes of the measuring electronic tacheometer before the mirror and behind it (to the sighting target) were horizontal. Otherwise, large deformations around a horizontal axis will distort the measured horizontal directions. The well-known error formula ΔA in horizontal direction could be applied here depending on the inclination of the vertical axis of the electronic tacheometer β in the transverse direction and the angle of the sighting axis ν:

$$\Delta A = \beta \cdot tg\nu \tag{5}$$

Upon possible device tilts β due to alidade unbalance 30" and off-levelling of the sighting axis 1°, we will obtain that can be considered valid. Moreover, this error will be also ultimately reduced in times.

One of the following electronic tacheometers was taken for research. The measuring instrument was the electronic tacheometer Leica with a two-second accuracy. The distances from the mirror to the electronic tacheometer and to the sighting target were 1.8 and 20.2 m, respectively. Angle γ was 5 °. Coefficient k_1 for these data was 1.84.

The measurements were carried out for three options with different moments of force leading to various alidade imbalances:

- Regular embodiment in which the unbalance quantity is 0.27 N·m
- An option with zero force moment in which the alidade was equilibrated by additional 260 g weight at a distance of 10 cm from the device axis
- An option in which with the same additional weight of 260 g on the other side of the device at a distance of 13 cm additional force moment equal to 0.34 Nm has been created, resulting in total force moment of 0.61 Nm
- Hence, we obtain the coefficient $k_2 = 2.26$

Measurements of these three options were carried out for 2 measuring circuits:

- The device with the mirror was fixed above the support but below the alidade (the mirror on the support)
- The device with the mirror was fixed between the support and the tripod head (the mirror on the tripod)

Two measurements were performed for each option. In one measurement, the alidade of the tested electronic tacheometer turned to angles α_i from 0°-360° through 30° (all 13 states). For each position, a crosshair was aimed with use of the measuring electronic tacheometer through a mirror to a luminous sighting target with a diameter <0.5 mm and readings for horizontal and vertical circles were recorded to the device memory.

RESULTS AND DISCUSSION

The main results are shown in Fig. 2. Range of support swing with tripod around a horizontal axis is 30"

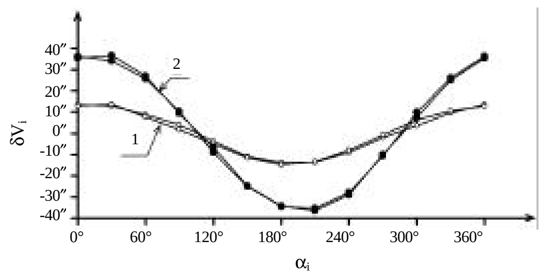

Fig. 2: Curves for deviations along the vertical circle; 1: regular force moment; 2: increased force moment

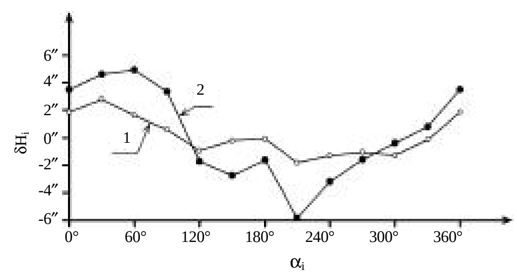

Fig. 3: Curves for deviations along the horizontal circle; 1: regular force moment; 2: increased force moment

(Fig. 2, curves 1). Swing range for option with increased force moment was about 70" (curves 2) that agrees well with the value of $k_2 = 2.26$. Phases of two sine waves are good fit, too. Analysis of other curves show that deformation of the support and the tripod are approximately equal.

Figure 3 shows the differences between the deviations along the horizontal circle. Differences were found based on the average values for the two methods of measurement. Deviations for the schemes with the mirror on the tripod were deducted from the deviations for the circuit with the mirror on the support. As a result, the chart has deviations caused by the support deformations only. Range of fluctuation deviations was 5" (curve 1) that can be explained by errors of measurement, if desired. However, in the option with increased force moment fluctuation range is 10" (curve 2) where taking into account k_2 we would get the value of 4" close to the above 5". And here, the phases of two sine waves are close together.

For the option with zero force moment, results are to be expected, so the graphics are not shown. Both graphics for HA and VA range near zero, mainly due to measurement errors.

The value of the resulting azimuthal deformation is small but it is elastic deformation which can be more for other devices: only one device was arbitrarily taken for the experiment yet. However, azimuthal elastic deformations identified relate only to that part of the support on which the device with the mirror is fixed. However, in addition there also may be azimuthal deformations in other parts of the device located in the structural circuit of the instrument from the support to the part carrying the coded horizontal circle. Development of techniques and execution of this research is planned for the future.

CONCLUSION

The researchers of the paper have measured the moments of forces caused by imbalance of the alidade for Leica, Nikon, Sokkia, Spectra, Stonex, Topcon, Trimble type devices. The moments of force were within the range from 0.07-0.27 Nm. Researches made before for one of the instruments showed the support tilt oscillation value (with tripod) up to 80″.

Thus, the experiment has showed with a high degree of reliability that because of the alidade unbalance there are elastic turns of the electronic tacheometer support not only around the horizontal axis within the range of about 30″ or more which have practically no influence on the accuracy of vertical angle measurement but also azimuthal turns, which directly lead to additional errors in measuring horizontal angles although, the azimuthal turns value order is less.

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