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SOURCES OF ERRORS IN ANGLE MEASUREMENT AND MEASUREMENT OF ANGLES BY THE METHOD OF CIRCULAR SETS

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ANNOTATION: *This article discusses the sources of errors that occur during angle measurement in geodetic and topographic works, as well as the principles of measuring angles using the circular acceptance method, also known as the Struve method. The paper highlights both instrumental and observational errors, along with techniques to minimize them. The Struve method, which allows for more accurate determination of horizontal angles by using double observations from two circle positions, is explained in detail. The importance of precision and error correction in geodesy is emphasized.*

KEYWORDS: *Angle measurement, Struve method, circular acceptance, geodesy, measurement errors, theodolite, accuracy, horizontal angle.*

No matter how carefully angle measurements are carried out or how precise the measuring instruments may be, it is impossible to completely eliminate errors. To ensure the required level of accuracy for predetermined measurements, it becomes necessary to develop specific rules or a precise methodology that allows either the elimination of these errors from the results or the reduction of their influence to an acceptable level.The sources of measurement errors are generally divided into three categories: personal errors, which arise due to the imperfection of the observer's sensory organs; instrumental errors, resulting from the imperfection or improper adjustment of the instruments; and external (environmental) errors, caused by the influence of the surrounding environment.Personal errors depend on the observer's vision and perceptual ability. One of the physiological parameters of the human eye is the smallest visible angle — that is, the minimum angle at which an observed object can be distinctly seen. This parameter largely depends on the brightness of illumination of the observed object. Therefore, it is essential to ensure that the clarity and brightness of all observed targets are as uniform as possible.Another important physiological factor is the ability of the observer to detect small displacements of a point — this defines the pointing error of the telescope. The effect of this error can be minimized by repeating the observations of all directions multiple times.Instrumental errors are related to

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imperfections in the construction or adjustment of the measuring instruments. When measuring angles, the theodolite must satisfy the following geometric requirements:

- The centers of rotation of the alidade and the horizontal circle (limb) must coincide, and both must coincide with the center of the graduated circle.
- The vertical axis of the theodolite must coincide with the plumb line passing through this center.
- The plane of the limb and the axis of the telescope rotation must be perpendicular to the vertical axis of the instrument.
- The rotation axis of the alidade must remain fixed during the entire measurement.
- The divisions on the limb must be evenly spaced and accurately marked.
- A full revolution of the optical micrometer head must correspond exactly to one limb division.
- The crosshairs in the reticle must be located in the plane of collimation.

Any deviation from these geometric conditions gives rise to instrumental errors. These errors can cause systematic distortions in the measured angles if not properly adjusted or corrected.[1]

The essence of this method is as follows. With the limb fixed, the alidade of the theodolite is released and rotated clockwise, while the sighting telescope is aimed successively at points 1, 2, 3, … (Figure 5.1), and finally at point 4.

These measurements together constitute the first half-acceptance.Then, the telescope is rotated through the zenith so that the vertical circle takes the opposite position. The alidade is then rotated counterclockwise, and the telescope is again aimed at the same points, but in the reverse order — 1, 4, … and finally at point 2 — taking readings again; this completes the second half-acceptance.

Both half-acceptances together form one complete acceptance.If, at the end of each half-acceptance, the telescope is again aimed at the initial point 1 and another reading is taken from the limb — that is, if the horizon is closed — such a measurement is called angle measurement by the circular acceptance method.The circular acceptance method was proposed in 1816 by the great Russian geodesist and astronomer Academician F. G. W. Struve. This method is used in almost all countries of the world. In the CIS countries, it is applied in the construction of state geodetic networks of classes II to IV.[2]

Although the technique for engraving limb circle divisions has reached a high level of perfection nowadays, both random and systematic errors can still occur during the process of marking the divisions. The random errors in the limb markings are several times smaller than the systematic ones. According to research, the root mean square value of random errors does not exceed ±0.5 seconds. Systematic errors

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have a periodic nature and follow a complex regularity.According to the state standard for theodolites, the total permissible error in the diameters of the horizontal circles should not exceed ±1″ for the T1 theodolite, ±1.5″ for the T2, and ±2.5″ for the T5.

To reduce the influence of these errors in angle measurement operations, the position of the limb is changed by an amount

δ=180∘m\delta = \frac{180^\circ}{m}δ=m180∘

(where m is the number of sets of observations), and the mean value obtained from all sets for each direction is taken as the final result.

The deviation of the theodolite's rotation axis from the vertical line causes the telescope's rotation axis to tilt, which in turn leads to errors in the readings taken from the limb during observation. In this case, the reading taken from the limb contains an error calculated by the formula:

v″=v″·cotgzv" = v" \cdot \cot g_zv″=v″·cotgz

where v is the deviation of the telescope's rotation axis expressed in half-divisions of the alidade, and is determined based on the alidade circle.

If the zenith distances of the observed points differ by more than 2° from 90°, a correction for the inclination of the rotation axis must be applied to the readings of the horizontal circle. [3]

The vertical refraction error can have a significant value. It may cause errors of up to two minutes or more in measuring zenith distances. To account for its effect, corrections are applied to the measured zenith distances. The refraction coefficient has been determined many times in practice and is usually taken as 0.14.Measurements of zenith distances should be performed under conditions where the refraction coefficient remains constant and stable.Lateral refraction typically ranges between 0.5–0.7 seconds, and under unfavorable conditions, it can reach 5–7 seconds. The value of lateral refraction varies for each direction during the day and also from one day to the next. Lateral refraction reaches its maximum value on hot, windless, and clear summer days. On cloudy, cool days with light breezes, its influence decreases.No correction is applied for lateral refraction because determining its coefficient is extremely difficult. To minimize the influence of lateral refraction and obtain more accurate observation results, it is necessary to follow empirically established practical rules.Changes in the temperature of the theodolite, especially uneven heating of its individual parts, lead to alterations in their relative positions. As a result, this causes distortions in the geometrical configuration on which the instrument's design is based.

To reduce the impact of temperature variations on the instrument, it should be protected from direct sunlight using a special sunshade or cover. [4]

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CONCLUSION

Angle measurement accuracy is essential for precise geodetic and engineering work. Understanding and reducing the sources of measurement errors ensure the reliability of results. The Struve circular acceptance method remains a highly efficient and scientifically grounded approach to improve the accuracy of angle measurements by compensating for systematic instrumental and observational errors. Continuous application of such methods contributes to the development of precise and reliable surveying technologies.

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