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Uncertainty evaluation of proposed setup for the calibration of vertical angle measuring systems by using means for the flat angle calibration

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ABSTRACT

Precision angle measurements performed by using total stations is a field showing a lot of potential. Horizontal angle measuring system calibration is a well documented and researched field however vertical angle measuring system calibration tends to lack proper investigation. The paper deals with the analysis of modern calibration methods of vertical angle measuring systems. New setup for the calibration of vertical angle measuring system of the total station using horizontal angle calibration means is presented in the paper. The principle of the method is explained and the uncertainty evaluation as well as preliminary results are given in the paper. The advantages and weaknesses of this new setup are discussed.

1. Introduction

Total stations (TS) are electronic distance and angle measuring devices commonly used in geodetic measurements. Although these instruments are mostly used for outdoor measurements, good optics and precision angle measuring systems motivates scientists to use total stations in laboratory measurements. Since there are two angle encoders (horizontal and vertical) embedded in total stations it is very important to perform the calibration of these instruments in order to determine systematic errors.

As previous research showed, most of the methods in angle metrology deal with the flat angle calibration [8]. However, calibration of vertical angle measuring systems is a challenging task for scientists.

Analysis of means and methods for angle calibration led to a conclusion that angle calibration should be performed using standard means such as Moore's Precision Indexing Table, polygon or other reference mirror and an autocollimator. For vertical angle calibration it is quite difficult to combine such instrumentation in a vertical plane. Therefore, an apparatus with the special frame which allows the horizontal position of the total station while performing the measurements was created at Korea Research Institute of Standards and Science. The novel approach for the calibration of vertical angle measuring systems by using the means for flat angle calibration is presented in this paper.

2. Vertical angle calibration methods

There are only a few comparators designed for vertical circle calibration. Such vertical circle comparator (VCC) was created as the standard in order to perform precise calibration of vertical angle measuring system of robotic total stations and laser trackers in ESRF, France. This comparator is designed to measure vertical angles in the range of 90° ± 45° and 270° ± 45° because this is the range mostly used while performing vertical angle measurements. An

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instrument to be calibrated is placed against the vertical circle comparator and the reflector is mounted on the adjustable part of the comparator. During the calibration procedure vertical circle readings are compared with the vertical displacements of its spherically mounted retro-reflector which are measured by the interferometer. The horizontal distance between comparator and the total station is measured by using distance meter calibration bench. While changing the position of the reflector different vertical angles can be measured. The VCC calibration procedure compares the total station's vertical circle readings with the angles determined based on vertical displacements of its reflector and the calibrated distance between the VCC and the device to be calibrated. The uncertainty of vertical angle measuring system calibration was determined to be 1.4″. However, the drawback of this method is that this comparator is designed to calibrate vertical angle measuring systems of the robotic total stations, therefore, minimal distance is 2.5 m which reduces the vertical angle calibration range to ±23.75°. The expanded uncertainty of vertical angle measuring system calibration using this vertical circle comparator is 1.65″ ($k = 2$) [5–7].

Another method for vertical angle measurement system calibration developed by Leica, Switzerland is based on the mirror and autocollimator measurements. Practically, this principle was implemented by fixing a special mirror to the telescope of a total station which is mounted to special high precision theodolite testing machine on the top of the reference horizontal rotary encoder. This machine has two reference indexes (in horizontal and vertical planes) and a frame which enables autocollimator rotation around the TS to be calibrated in a vertical plane. TS's vertical encoder readings are compared to the reference vertical high precision indexing table readings. This method is implemented only by using special fully automatized Theodolite Testing Machine (TPM) which fulfills the condition of orthogonality of the axes. The standard deviation of 0.058″ for horizontal angles and 0.091″ is possible to achieve by this machine because of its unique structure and precision [3,4].

At National Metrology Center in Singapore the vertical angle calibration method where indexing table and a collimator is used was developed. A special fixture is used to ease the alignment process and minimize effect from compound angle. The expanded uncertainty obtained by this method is $U_{95\%} = 2.0''$ ($k = 2$) and the vertical angle calibration range of 90 ± 30° is possible to achieve [10].

3. Proposed setup

3.1. Principle and design of the system

The proposed angle measuring system is based on well-known and reliable angle measuring technique described in standards, latest angle metrology related papers and official reports of famous metrology institutes. The main principle of angle calibration is comparison of reference angle and measured angle. The reference angle can be obtained by using various techniques and instrumentation. One of the main techniques used for horizontal angle measuring system calibration of total station is comparing measured angle with the reference angle created by the indexing table. 1440 Precision Index is considered a principal angle standard and is based on the circle division into 1440 even parts with the pitch of 15′ [9]. The instrument is guaranteed to be accurate to within ±0.1″ at any of the 1440 indexed positions. Such accuracy is attained by controlling all the components of the rotary table. The serrated – tooth divider is the crucial component of Moore's 1440 Precision Indexing Table. This divider employs two face gears of identical shape and spacing of teeth. One member is displaced axially to disengage the teeth and then rotated radially to the desired angle. When two opposed faces of the gears are brought into forced engagement, they become locked in place, preventing rotation or side movement [11,12]. Since indexing tables are commonly calibrated by using autocollimators and reference mirrors, it was decided to use this principle for calibration of vertical angle measuring system of total station.

Because of the complicated design of total stations it is quite challenging to perform high quality calibration of vertical angle measuring systems. This new set up is based on principles of horizontal angle calibration.

The novel component of this angle measuring system is a special apparatus fixed on the top of Moore's 1440 Precision Indexing Table. This apparatus has a weight balanced structure and special frame which is designed to fit a total station in horizontal position. The special mount for fixing total station's tribrach is installed in this vertical angle measuring system as well as six adjustment screws, three on each side, of the frame to support and level upper part of a total station (Fig. 1).

Leveled total station is fixed to the apparatus horizontally. To perform autocollimator measurements there is a need to fix the mirror on the TS's telescope. Therefore, the special mirror mount was designed to fit the total station's telescope (Fig. 2).

This mirror mount has four adjustment screws as well as screws for fixing the mount to the telescope of the total station. The mirror is fixed to a special recess designed for it. The adjustment screws are in the plane parallel to the mirror located in four points around the mirror in order

Fig. 1. Components of the vertical angle measuring system.