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INTERFEROMETRIC BENCH FOR CALIBRATION OF DISTANCE MEASURING INSTRUMENTS

Lauryna Šiaudinytė[1], *Domantas Bručas*[2], *Mindaugas Rybokas*[3]

[1]Vilnius Gediminas Technical University, Institute of Geodesy, Sauletekio al. 11, LT-10223, Vilnius, Lithuania, lauryna.siaudinyte@vgtu.lt
[2]Vilnius Gediminas Technical University, Institute of Geodesy, Sauletekio al. 11, LT-10223, Vilnius, Lithuania, domantas.brucas@vgtu.lt;
[3]Vilnius Gediminas Technical University, Institute of Geodesy, Sauletekio al. 11, LT-10223, Vilnius, Lithuania, mindaugas.rybokas@vgtu.lt

Abstract – Diagnostics of precision measurement device accuracy problems, caused by deviations of measurement components from the reference dimensions is a major topic in manufacturing as well as scientific field. Such deviations are harmful, if untreated.

The paper deals with the analysis of developed indoor facilities for measuring tape calibration. A new interferometric bench suitable for calibration of electro-optical distance measuring instruments is presented in the paper. The design of both the bench and the carriage is discussed and the scopes of application are presented.

Keywords: length measurements, cyclic error, calibration, EDM.

1. INTRODUCTION

Based on the requirements for calibration laboratories, set by ISO:17025 the setup of calibration laboratories has to be built in a way that the measurements made by the laboratory are traceable to the International System of Units (SI) in order to be recognized as competent. Laboratories, meeting this and other domain-specific criteria are issued by with a calibration certificate. Typically, a measurement standard is used as a reference for establishing measured quantity values as well as uncertainties associated with the measurement for other quantities of the same kind. It establishes metrological traceability, using other measuring systems, instruments and standards. In accredited laboratories distance measurements are traceable to the meter [8, 9].

The reference meter is defined as the length of the path travelled by light in vacuum during the time interval of 1/299 792 458 of a second. The spectrum the wavelengths of visible electromagnetic radiation (visible light) varies from 390 nm to 700 nm. The color of light is determined by its frequency or wavelength. Typical solution in order to have a stable and controlled light is usage of a laser light source. It is used as a standard due to its’ high stability of the wavelength (frequency uncertainty is less than $1 \cdot 10^{-10}$). The discretion of linear dimension measurement using a laser interferometer reaches up to 0.01 µm. Such devices are numerically controlled therefore corrections due to temperature, pressure and humidity variations are applied automatically. Moreover, the influence of thermal expansion for the accuracy of measurements is taken into account as well.

2. PROPOSED BENCH FOR LINEAR MEASUREMENTS

The accuracy of geodetic measurements can be increased by reducing the errors, caused by the instrument. It is achieved by configuring the instrument as well as calculating corrections based on the results. Corrections that are constant or dependent on the measured distance can be implemented for usage with EDMs (Electronic Distance Meters) found in total stations.

Numerous indoor facilities for distance calibration exist in various institutes. They operate by comparing the results of instruments under the calibration with the distances measured by an interferometer. Korea Research Institute for Standards and Science has developed a 50 m linear interferometric facility for the calibration of surveying tapes. This facility provides an automated solution consisting of an optical system mounted inside the carriage with the focusing installation for the observation of tape lines. It is also used for the EDM calibration [10]. Similar example is presented at the National Metrology Institute of Germany where the reference distances are measured by incremental laser interferometer [16].

In Czech Technical University in Prague the EDM calibration facility was established with 16 concrete pillars with centering plates on the top and with 38 m in total length of measurable distance [2]. However, since this facility is not equipped with a carriage sliding along the rails, only fixed distances can be measured. These pillars are established at the pitch of around 2.5 m and therefore, might include some errors in between.

In Lithuania, so far, there is Kyviskes long distance calibration outdoor baseline with the longest distance in the country, reaching 1320 m [4]. However, indoor test bench is still under development. Certain premise-wise limitations at Institute of Geodesy, VGTU, suggest that an indoor calibration facility should be smaller in dimensions. Therefore, it has been decided to establish 13 meter interferometric bench for cyclic error determination of EDM described further in the paper.

2.1. Construction of the bench

The test bench implements the distance meter cyclic correction stand composed of multiple well established stands as the base for linear movement rail. The rail itself is a standard aluminum profile made for steel roller bearing linear guides to roll the mounted moving carriage.

Usage of aluminum components is based on the requirement for the system to be low-weight. Since the newly developed system is installed on the stands and pillar coming from the previous setup. As these components fully comply with the design of the new system, reusing these components is a cost-effective solution, keeping the overall quality at the desired level, as the distances between the stands have been already calibrated. However, reusing the components comes with a drawback – the older systems' stiffness issues can have effects on the accuracy.

The linear displacement equipment setup of the proposed test bench is presented in Fig. 1, where the stands from the old setup are marked red.

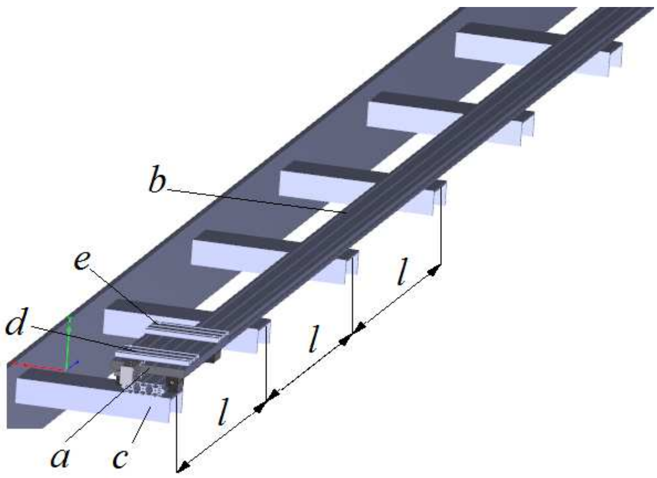

Fig. 1. Linear displacement equipment of the test bench

The profile rail is flexibly connected to each pillar (with the step of 1 meter) and precisely leveled. Preliminary design of linear calibration bench and its components (a – moving carriage, b – rails, c – supports established every l=1 m, d – reflector mount for total station measurements, e – corner cube mount on the carriage to create the path for split laser beam is shown in Fig.1.

2.2. Construction of the carriage

A carriage that moves along the rails of the bench is an aluminum body, equipped with precise ball bearings. In this case the main component that ensures the smooth motion of the carriage is a motorized linear air-bearing. The key components that influence the precision of overall system, such as the vertical and horizontal straightness as well as rotational error have to be determined before using the carriage for the calibration of length measuring instruments [5]. Aluminum is the preferred choice in this case as it offers lower moving mass thus minimizing the inert influence on the rail profile. The car movement is automated by using stepper motors (with coarse distance determination) so the car can be positioned at any linear position within the length of the bench.

Precise car position is determined by a stationary fixed interferometer and its' mirror mounted on the moving car.

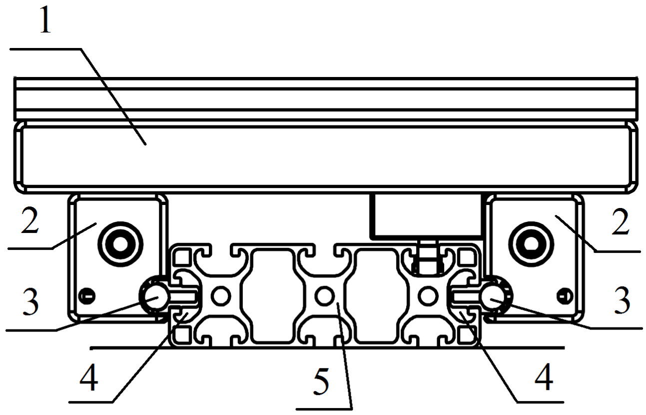

Fig. 2. Schematic view of the carriage and sliding system

1 – anodized aluminum carriage plate; 2 – bearing units consisting of pairs of centric and eccentric bolts. Bearing units are connected together by a carriage plate to form a sliding carriage; 3 – stainless steel hardened and polished shafts which are used as a rails for carriage to slide; 4 – anodized aluminum shaft - clamp profiles which are used as a basis for linear slides; 5 – anodized aluminum profile which provides the deflection of 0.03 mm for 1 meter distance with the carriage weight of 5 N. Therefore, the bending stress is 0.52 N/mm^2.

3. APPLICATION OF THE DEVELOPED BENCH

Formerly it was typical for interferometric benches to be designed for tape calibration under the laboratory conditions. Lately the trend is to create multi-functional benches. At the Institute of Geodesy, VGTU a multi-functional calibration bench is under development. Application possibilities are presented further in this section.

3.1. Cyclic error determination

Cyclic errors as well as short periodic errors are described by a periodic function, consisting of the wavelength and the difference of the phases between reference and measured signals. However, it brings along the phase measurement error. The magnitude as well as the sign of the error is dependent on the location where the measurement is made. Modern EDM instruments offer measurements with relatively small cyclic errors.

Cyclic error tends to increase along with ageing of the components of the device. Cyclic error is calibrated to determine instruments' behavior while measuring different distances.

All measured distances are compared with known values obtained by higher order measurements. Finally, by computation of the discrepancies (measured - true) the amplitude of the cyclic error can be determined by variations around the mean value of the additive constant [14].

Since the proposed bench is intended to be used for the calibration of total stations, the best way to determine cyclic error is to measure distances at certain pitch by the instrument under calibration and compare the results with the reference distances provided by a laser interferometer. The differential phase angle between exiting and returning signals can be with the size of a fraction of the modulation wavelength. Moreover, the number of wavelengths that comprise the whole distance can be determined by repeatedly performing measurements at lower frequencies [11].

The proposed bench is 13 meters long. Distances between the reference stands were calibrated with the uncertainty provided in Figure 3. Wild Distomat DI 2002 and Wild Theomat T2002 tacheometer along with Wild GPH1AP reflector were calibrated at the Nummela Standard Baseline and used for distance measurements. In total 70 distances were measured performing repetitive measurements from stands 0, 2, 5, 7, 8. Calibration results are shown in Figure 3 where averaged measured distances between the stands as well as measurement uncertainty are presented.

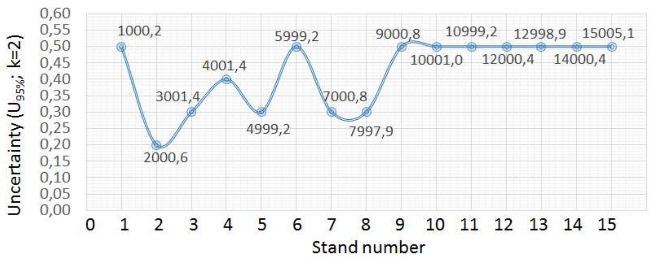

Fig. 3. Uncertainties of measured distances

These indoor facilities can be used all electronic distance measuring equipment. The EDM of laser scanners are also calibrated using this cyclic error determination baseline. The target are placed on established stands and scanned. Each scanned target consists of a cloud of approx. 39000 points which are used to determine the coordinated of the target centers. Then measured distances are compared with the calibrated distances between the cyclic error determination baseline stands [1].

3.2. Vertical angle measurements

The method for calibration of vertical angle measuring systems of geodetic instruments which was developed in Institute of Geodesy of Vilnius Gediminas Technical University can also be applied by using proposed bench.

This method proposes the arrangement to create the reference standard for angle measurement suitable for vertical angle calibration purposes in laboratory environment [6]. This method is suitable for relatively small angle measurements and is based on trigonometric determination of the reference angle by using standard means. It is a comparison of the angle measured by total station and the reference angle determined by measuring two distances – horizontal (distance between TS vertical axis and vertically placed scale) and vertical (distance between the lines of the vertically placed reference scale). The principle of the method is shown in Figure 4 [3].

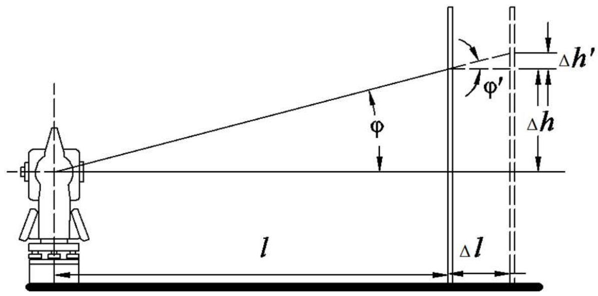

Fig. 4. The setup for vertical angle calibration

The reference angle determination based on measuring horizontal and vertical distances can be expressed:

$$\varphi = \arctan \frac{\Delta h}{l} \tag{1}$$

where Δh – vertical distance determined between the scale grating; l – horizontal distance between the axis of the TS and the reference scale.

Using this method, reference 1 meter graduated scale bar is placed vertically using special mount for stability and leveling on the carriage. The graduated scale must be perpendicular to the optical axis of the total station.

The total station is then placed and leveled on a pillar at the end of the rails. It has to be placed at such height that the center of the cross-line of its telescope in horizontal position would match the center of the central line of the vertically placed graduated scale. The horizontal distance between the total station and the reference scale (*l*) must fit the focusing range of the total station (TS). The closer vertical reference scale is to the total station, the bigger range of TS vertical angle encoder can be calibrated [3].

The particular angle is observed by pointing the telescope of the total station to the line of the scale. After fixing the telescope, reference scale is moved until another line of the reference scale is matched with the reticle center of the TS. As it is seen from the Fig. 4 the reference angle (φ') can be expressed:

$$\varphi' = \arctan \frac{\Delta h'}{\Delta l} \qquad (2)$$

where Δh' – known vertical distance between two calibrated scale lines; Δl – horizontal displacement of the reference scale. After such procedure measured angle is compared to the reference angle which is determined by using standard means such as reference scale and laser interferometer.

3.3. Calibration of digital levels

Digital levels are commonly used in the field of geodesy and survey. Since they are optical devices suitable for height difference determination, they have to be calibrated. Calibration under the laboratory conditions ensures reliable results in controlled environment. Special coded, bar-coded staffs are used to perform measurements with the digital levels. Various codes depend on the manufacturer [7]. These staffs are usually 3 meters to 4 meters height. Therefore, it is quite complicated to prepare all the instrumentation for indoor calibration. Many calibration laboratories (i.e. in Finland, Austria, US) uses special comparators to ensure verticality of the scales [12, 13, 15]. Since space efficiency is a common issue there were developed some systems suitable to perform the calibration in horizontal plane. For this purpose the pentaprism is used to direct the field of view to the staff which is placed horizontally.

The linear test bench under development could be used for digital level and staff calibration by aligning pentaprism on the carriage and placing the staff horizontally along the rails.

4. CONCLUSIONS

Numerous setups worldwide for calibration of EDMs have been analyzed to define the best suited design for a calibration bench.

An aluminum component based setup is proposed for implementation at the Institute of Geodesy, VGTU.

This interferometric bench was designed for EDM calibration on the basis of formerly established and calibrated stands. Building upon the existing infrastructure components provides a cost-effective solution. Due to the concerns premise-wise, this design offers a compact, space saving facility that provides competitive results.

The scope of the proposed setup is defined. It includes methodology for cyclic error determination, vertical angle measurements and calibration of digital levels.

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